

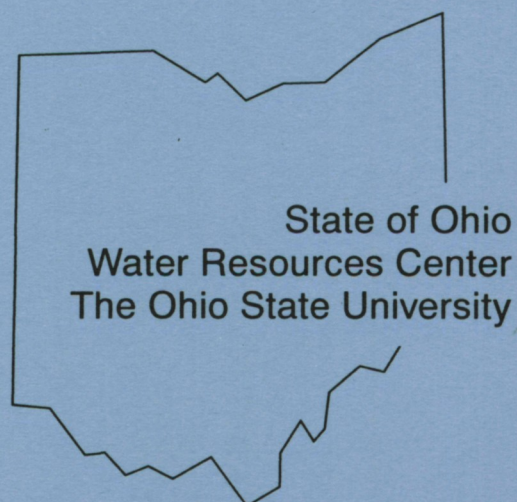
WATER
WATER
WATER
WATER
WATER
WATER
WATER
WATER
WATER

Report No. GRO-2691-02

**FISCAL YEAR 1997
PROGRAM REPORT**

Earl Whitlatch
Director

United States
Geological Survey



Report No. GRO-2691-02

**FISCAL YEAR 1997
PROGRAM REPORT**

Earl Whitlatch
Director

United States
Geological Survey

State of Ohio
Water Resources Center
The Ohio State University

Report No. *GRO-2691-02*

**Fiscal Year 1997 Program Report
Grant No. 1434-HQ-96-GRO2691**

for

**U. S. Department of the Interior
Geological Survey**

by

**Ohio Water Resources Center
The Ohio State University
Columbus, OH 43210-1057**

Earl Whitlatch, Director

June, 1998

The activities on which this report is based were financed in part by the
Department of the Interior, U. S. Geological Survey,
through the Ohio Water Resources Center.

The contents of the publication do not necessarily reflect the views and policies of the
Department of the Interior, nor does mention of trade names or commercial products constitute
their endorsement by the United States Government.

FISCAL YEAR 1997 PROGRAM REPORT

**Ohio Water Resources Center
The Ohio State University
Columbus, Ohio**

ABSTRACT

Most of Ohio's water problems are associated with water quality. Of primary concern are the sediments, nutrients and acids in the surface waters from urban, agricultural and mining areas, and toxic and hazardous wastes that threaten the ground and surface waters. The research and technology transfer program consisted of the following activities:

One two-year research project was funded in the Regional Competition in 1996 and 2 two-year projects were selected in 1997. The 1996 project by Professor Yu-Ping Chin is "Sunlight Induced Degradation of Agricultural Pollutants in Wetlands" is the first project in this report. This research project supported one research student in the Department of Geological Sciences at the Ohio State University. The 1997 projects awarded in the regional competition are: Economic and Hydrologic Analysis of Integrated Wetland Reservoir and Subirrigated Agricultural Production Systems by Drs. Larry C. Brown and Marvin T. Batte of The Ohio State University, College of Food, Agricultural and Environmental Sciences. This research project provided partial support to 10 students - 5 part-time Undergraduates, 2 Masters, and 3 Ph.D. The research project by Drs. Jonathan Levy and Robert H. Findlay of Miami University, Geology Department, is: Degradation of Groundwater Quality from Pumping-Induced Surface-Water Infiltration: Bacterial Contamination. This project provided support to one Masters student in Geology.

The technology transfer program disseminated information about water resources in Ohio to local and state decision-makers. Professional training and development was also provided to 1,000 water resources managers throughout the year.

The information transfer program has supported seminars, conferences, water education for K-12 education, provided support for professional water resource managers and newsletter for water researchers in Ohio. In addition, there were two 2-day facilitator workshops for 100 educators, and 69 six-hour workshops where 1,220 educators participated in water resources classroom activities. These people in turn provided water education to 30,500 Ohio K-12 students in the year.

Table of Contents

	Page
Abstract	i
Water Problems and Issues in Ohio	1
Program Goals and Priorities	1
Regional Research Priorities	1
1996 Regional Competition Report	
C-02 Chin-Yu-Ping, Sunlight Induced Degradation of Agricultural Pollutants in Wetlands	2
1997 Regional Competition Progress Report for Period:9/1/98 to 2/28/98	
C-03 Brown, Larry C. and Marvin Batte, Economic and Hydrologic Analysis of Integrated Wetland Reservoir and Subirrigated Agricultural Production Systems	20
C-04 Levy, Jonathan, et al.; ; Degradation of Groundwater Quality from Pumping Induced Surface-Water Infiltration: Bacterial Contamination	34
D. Information Transfer Program	56
Water Luncheon Seminar	
Water Management Association of Ohio	
Ohio Water Education Project	
Cooperative Arrangements	
Water Resources Center Advisory Board	
E. Student Support	63
G. Notable Achievement and Awards	64

Water Problems and Issues in Ohio

Water is one of Ohio's most important natural resources. Bounded on the north by Lake Erie and on the south by the Ohio River and containing other extensive ground and surface waters, Ohio has an adequate supply of water to meet its immediate needs. However, the combination of large, heavily industrialized urban centers; extensive agricultural activities; high volume coal production and large coal reserves; and the associated demands of new energy production continues to cause concerns related to water quality and water management. In addition, extreme hydrologic events cause localized problems of both excessive water and deficiencies at times.

Program Goals and Priorities

The 1997 program objectives as outlined by recent legislation is to:

- A. Conduct research relative to important water resource problems of the Region
- B. Promote the dissemination and application of the results of the research involving these problems; and
- C. Assist in the training of scientists in relevant water resource fields.

Regional Research Priorities

- 1. Wetlands processes and management
- 2. Watershed processes and management
- 3. Drinking water quality and availability and source protection
- 4. Wastewater treatment for small communities
- 5. Urban water infrastructure systems
- 6. Non-point source pollution reduction - better management practices
- 7. Groundwater and surface water quality
- 8. Remediation of contaminated sources
- 9. Conjunctive use - ground and surface water interface or connectivity
- 10. Irrigation systems and water-use efficiency
- 11. Atmospheric contamination of water sources

Proposals that include a strong educational component (student support) and/or are from faculty beginning their careers receive some preference.

SYNOPSIS

Start: 09/96

End: 08/98

Project Number: C-02

Title: Sunlight Induced Degradation of Agricultural Pollutants in Wetlands

Investigators: Yu-Ping Chin, The Ohio State University

Congressional District: Fifteenth

Focus Categories: WL, NPP, WQL

Descriptors: Wetlands, Water Quality Control, Pesticides, Nonpoint Source Pollution, Water Quality, Photolysis

Problem and research objectives:

Non-point source contamination is difficult to control because it may be distributed across large areas of a watershed. Wetlands, however, may provide a means of managing water quality since the hydrology of a watershed will often result in the collection of water from diffuse sources into basins before final discharge to other receiving waters. Numerous researchers have noted an improvement in water quality as water passes through wetlands, and have attributed this phenomenon to a combination of physical and chemical removal mechanisms.

In wetland surface waters, sunlight induced reactions may have a significant contribution to the chemical transformation of agricultural pollutants. Wetlands generally have large surface areas and shallow depths that would allow significant sunlight exposure and penetration throughout the water column. Thus, wetlands may provide an important medium for commonly used agricultural chemicals to undergo **direct** phototransformation (Simmons and Zepp, 1986; Hwang *et al.*, 1987). Moreover, wetlands, in comparison to other water bodies, are rich in photosensitizers, *e.g.*, dissolved organic carbon (DOC) and nitrate, which are capable of absorbing sunlight and catalyzing the transformation of organic compounds by **indirect** photolysis. Valentine and Zepp (1993) have attributed observed high near-surface photoreactivity in wetlands to high levels of DOC.

Objectives. The focus of this research is to examine and evaluate the photolytic transformation of non-point source pollutants in wetland surface waters. Specific objectives of this research are as follows:

- *elucidate the role of direct photolytic degradation of some commonly used agrochemicals (carbaryl, atrazine, and alachlor) at wavelengths present in sunlight;*
- *quantify and qualify the reactants (i.e., potential photosensitizers and transient quenchers) found in a chosen wetland site;*
- *conduct photodegradation experiments in the presence of these reactants from this site;*
- *characterize the chemical kinetics and mechanisms of these direct and indirect photolytic processes.*

Carbaryl was chosen because it is a widely used carbamate insecticide in Ohio (USGS, <http://water.wr.usgs.gov/cgi-bin/switch/use.cgi>) and capable of participating in direct (Zepp and Cline, 1977) and indirect photolysis (through its reaction with HO•) (Mabury and Crosby, 1994).

Methodology:

Collection of Wetland Raw Water. The field site selected for sampling wetland surface water was Old Woman Creek Estuarine Reserve (OWC) which is a 30 hectare wetland located on the south shore of Lake Erie, 5 km east of Huron, OH (Figure 1; web page reference). Approximately 69 km² of agricultural land drains into OWC's basin and subsequently, it receives a significant amount of suspended solids and pesticides (D. Baker, personal communication). Sampling sites were chosen at the inlet, interior (railroad), and outlet of the wetland. Samples were collected on June 17, 1996, which corresponded to the time of spring runoff (Kreiger, personal communication), and August 7, 1996. Raw water samples were collected in 4-L amber glass jugs, placed on ice, and transported to OSU. Samples were stored at 4°C until use.

Characterization of Wetland Raw Water. Wetland water samples were filtered through a glass fiber filter (Gelman A/E) prior to analysis and use. Samples were analyzed for dissolved organic carbon (DOC) using a Shimadzu TOC 5000 Analyzer. The light absorbing properties of the DOC were assessed with UV/VIS spectrophotometry (Varian Cary 1). Samples were scanned in quartz cuvette from 200 to 600 nm. The collected absorptivities were used to calculate attenuation coefficients and light screening factors appropriate for each natural water sample. Samples were analyzed for nitrate via reverse phase high pressure liquid chromatography (HPLC) (Schroeder, 1987). The limit of detection for nitrate in the wetland water samples was at 2.0×10^{-6} M.

Photolytic Reactions. Photochemical experiments were conducted using a merry-go-round reactor equipped with a mercury arc lamp (200-W) housed in a borosilicate immersion well (Ace Glass; Vineland, NJ) which screened out all light with $\lambda < 290$ nm. Light filters (CS 0-52; CS 7-60; Corning) were used to isolate the 366 nm wavelength. Light intensity was measured with chemical actinometry (*p*-nitroanisole/pyridine system) (Dulin and Mill, 1982) and found to be 6.46×10^{-6} einsteins/sec/L.

Reaction mixtures were prepared by spiking 50 μL of carbaryl stock solution (in acetonitrile; 5×10^{-3} M) to 50 mL of either phosphate buffered MilliQ water (MilliQ water system, Millipore Corp., Bedford, MA) or filtered OWC water yielding a nominal carbaryl concentration of 5 μM . Two mL aliquots of reaction solution were pipetted into pyrex culture tubes (13x100 mm) and were either stored in the dark in a temperature controlled water bath or irradiated at $\lambda = 366$ nm at a temperature of 27.5 °C. Test tubes were sacrificed periodically during the irradiation, and the reaction was quenched by the addition of 2 mL of acetonitrile and storage in the dark at 0° C.

Stability studies showed that samples may be stored up to 14 days without any significant degradation. Samples were assayed by HPLC for the parent compound and the detectable derivative (1-naphthol). A direct aqueous injection (25 μL) from each vial was made into the HPLC and analytes were detected with a programmable fluorescence detector (Waters 470). The mobile phase for the analysis was 37% acetonitrile : 63% MilliQ water, and the flow rate was 1.5 mL/min. The program for the detector was: initial through 4 minutes, $\lambda_{\text{excitation}} = 282$ nm, $\lambda_{\text{emission}} = 330$ for carbaryl (RT= 3.4 minutes); 4 minutes through 5.5 minutes, $\lambda_{\text{excitation}} = 292$ nm, $\lambda_{\text{emission}} = 462$ nm for 1-naphthol (RT = 4.5 minutes). Preliminary work in our lab have shown that this analytical approach is highly sensitive and provides linear detection over several decades of analyte concentration.

Data Analysis. Data were analyzed using *Scientist for Windows* v. 2.01 (MicroMath Scientific Software, Salt Lake City, UT). Rate expressions describing the observed kinetics were solved numerically using the EPISODE package, and observed rate constants for carbaryl degradation were determined from least squares fit (Powell algorithm) of the observed kinetic data to the pseudo-first order kinetic model. We did not consider it necessary to correct for carbaryl binding to dissolved organic matter since carbaryl has a relatively high solubility (0.05 g/L @ 20°C), and calculations based on the reported organic carbon partitioning coefficient (205–457 L/kg) showed that no less than 0.7% of the carbaryl spiked into the solutions would be associated with the organic matter present in the OWC water. Also, we did not correct for the partitioning of carbaryl into the headspace of the test tubes since carbaryl has a low Henry's law coefficient ($10^{-1.1}$ atm L/mol).

Principal Findings and Significance:

Several water quality parameters (e.g., pH, DOC, nitrate, alkalinity) were measured for the OWC samples (Table I). The UV/VIS absorption spectrum for each OWC sample was also recorded (Figures 2 and 3). The spectra of the June samples were dominated by the presence of nitrate (see insert #2 in Figure 2) as expected based upon the measured concentrations of nitrate in these samples (Table I). For the August samples, spectra more characteristic for DOM present in natural water samples were obtained.

Normalized (to the total amount of carbon present) molar absorptivities (ϵ) at $\lambda=280$ nm may indicate the amount of aromatic carbon present in natural water samples (Gauthier *et al.*, 1987; Traina *et al.*, 1990; Chin *et al.*, 1994). The low molar absorptivities (corrected for nitrate absorbance at 280 nm) observed for OWC water suggests that this material contains few aromatic moieties. As a comparison, International Humic Substance Society (IHSS) fulvic acids isolated from "blackwater" wetlands possessing high aromaticity (*i.e.*, Suwanee River) have extinction

coefficients at 280 nm at least 2x's greater than those measured here (Chin *et al.*, 1994). Moreover, even though the amount of DOC almost doubles in the water at all sites between June and August, ϵ remains approximately the same; thus, we believe that input of new NOM over time does not change its structural character. The normalized absorptivity, however, does decrease for both sample sets from the inlet to the outlet which suggests that the aromatic character of the NOM decreases as water passes through the wetland.

Previous results indicated that direct photolysis of carbaryl between $\lambda = 290\text{--}360$ nm may be a very efficient process (Armbrust and Crosby, 1991). Since our objective in this study was to identify the wetland water constituents participating in indirect photolytic processes, we chose to study photolysis at a wavelength ($\lambda = 366$ nm) where direct photolysis of carbaryl would be minimized (due to a small extinction coefficient) but the natural water was still able to attenuate light. Thus, we planned for the experimental conditions to favor indirect photolytic pathways, if any light enhancement was to be observed. The absorbance at $\lambda = 366$ nm was recorded to calculate the appropriate screening factors expected for each natural water sample during the photoreactions (Table I). The light screening factor (S_λ) can be used to correct the effect of light attenuation by natural waters on the direct photolysis rate. Application of S_λ to rate constants measured in distilled water can yield upper limit estimates of expected photolysis rates in the natural waters under same irradiation conditions. For the OWC water, S_λ ranged from 0.94–0.97 and indicated that light attenuation by natural water constituents would compete for only 3–7% of the photons impinging the samples in these laboratory experiments.

Results of Kinetic Studies: Rate constants were treated according to pseudo-first-order kinetics, and models fit reasonably well having R^2 's > 0.99 for all reactions (*e.g.*, Figure 4). The dark reaction for carbaryl in the natural water systems was shown to be quite significant (Table II). This result is not unexpected as carbaryl is known to undergo a significant base-catalyzed elimination reaction at pH's greater than 7 (Aly and El-Dib, 1971a, b; Wolfe *et al.*, 1978). Since the pH of the OWC water was found to be greater than 8 for all samples, contribution from the dark reaction would be large and, in fact, accounted for the largest percentage of the overall reaction in the light (Table II).

The light induced degradation of carbaryl was 1.1 to 1.4 x's higher than that in the dark for some of the natural water samples (Table II). Thus, the presence of light at $\lambda = 366$ nm did enhance carbaryl's degradation. The only daughter product observed and quantified was 1-naphthol (Figure 4). In the dark reactions, 1-naphthol accumulated in the solution phase resulting in good mass balances (Table II). Conversely, in the photoexperiments, 1-naphthol behaved as an intermediate and never accumulated to levels observed in the dark; thus, mass conservation based on this derivative alone was never achieved (Table II).

The contribution of any known environmental process to an observed rate of disappearance (k_{obs}) may be quantified by comparing the relevant first or pseudo-first order rate constant for the process in question (k_i) to the sum of the relevant rate constants (*i.e.*, Σk_j). Thus, the measured rate constant for the photoreaction of carbaryl in OWC water can be expressed as:

$$k_{\text{obs}} = \sum k_j = k_{\text{OH}^-}[\text{OH}^-] + k_{\text{direct}} + \sum k_i[\text{transient}]_i \quad (1)$$

where k_{OH^-} is the second-order rate constant for the base-promoted elimination reaction, k_{direct} corresponds to the relevant rate constant for the direct photolysis, $\sum k_i$ are the second-order rate constants for any reactive transient species i that results in the indirect photolysis of carbaryl.

From 5-24 percent of the overall reaction for the natural water samples showing light enhancement could be attributed to light induced pathways (direct and indirect). Under the assumption that the pH does not affect the direct photolytic pathway (Wolfe *et al.* 1978) the light screening factor can be applied to the measured direct photolysis rate constant (0.0034 hr^{-1}) obtained from an experiment conducted in MilliQ water to yield a predicted direct photolysis rate for each OWC sample.

The rate constants measured for waters showing significant light enhancement exceeded the simple sum of the k_{dark} and k_{direct} and indicated that indirect photolytic processes are important for these water samples. Subtraction of k_{dark} and k_{direct} from k_{obs} yielded a pseudo-first order rate constant that is representative of the indirect photolytic processes. The indirect photolytic processes may account from as little as 1 percent up to 23 percent the overall reaction in light and were apparently far more important in the June inlet and railroad samples than in the August inlet and railroad samples.

Effect of Natural Water Constituents: The possible reasons for the large range of reactivity should be interpreted within the context of the water samples. Analysis of the surface water revealed two possible photosensitizers: nitrate and natural organic matter (NOM). Nitrate is capable of producing hydroxyl radicals ($\text{HO}\bullet$) with quantum yields ranging from 0.08-0.015 when irradiated from 298 to 371 nm, respectively (Mabury and Crosby, 1994). Conceivably, in wetlands that receive agricultural runoff, nitrates may be sufficiently high enough to influence contaminant photolysis. Nitrate levels monitored in OWC from 1988-1990 ranged from 0.032-2.0 mM (Krieger, personal communication) and correspond well to this study (Table I). At the nitrate levels found in this study (7.9×10^{-5} - 4.7×10^{-4} M) the predicted production (noon-day sunlight at 40°) of relatively high steady-state concentrations ($\sim 10^{-15}$ - 10^{-17} M) (calculated from Schwarzenbach *et al.*, 1993) of $\text{HO}\bullet$ may be important in OWC compared with other water bodies ($\sim 10^{-18}$ - 10^{-16} M) (Zepp *et al.*, 1987).

A correspondence between nitrate level and observed reaction rate constant in the light was observed (Figure 5): the samples that showed the most significant light enhancement contained the highest levels of nitrate. The observed pseudo-first order rate constant, k_{obs} , decreased as nitrate level decreased through the wetland in the June samples (inlet to outlet). In the August samples, nitrate level was significantly lower, and its role as a photosensitizer would be expected to be significantly diminished.

Other water constituents may significantly influence the nitrate driven photochemical production of $\text{HO}\bullet$. Carbonate species (HCO_3^- and CO_3^{2-}) and NOM are important scavengers of $\text{HO}\bullet$ (Schwarzenbach *et al.*, 1993; Larson and Zepp *et al.*, 1988) and thus, reduce the steady state concentration of $\text{HO}\bullet$ available for pollutant transformation. Indeed, in considering the samples

that showed light enhancement, the DOC level seems to be inversely related to the measured k_{obs} (Figure 5). Since the OWC water had a relatively high alkalinity with total carbonate levels generally exceeding DOC by nearly an order of magnitude in some cases (depending on the water sample), carbonate species are probably the principle HO^\bullet scavengers for this water. As HO^\bullet is scavenged, the measured degradation of carbaryl with time would be expected to decrease. NOM has also been reported to quench excited states and scavenge reactive intermediates and photons (Miller *et al.*, 1980; Hwang *et al.*, 1987; Larson and Zepp, 1988; Woodburn *et al.*, 1993). As a consequence, very low steady-state concentrations these reactive species in natural surface waters have typically been observed (Faust and Hoigné, 1987).

Control photolysis experiments were performed to determine the influence of nitrate photochemistry on the photoinduced degradation of carbaryl. Photoreactions were performed in carbonate buffered ($(CO_3^{2-})_T = 3.6$ mM corresponding to the average amount measured in the OWC water) MilliQ water and OWC water at a pH (6) sufficient to inhibit the dark reaction pathway (Figure 6). In the “clean” (no NOM present) experiments, the effect of adding 0.40 mM nitrate to the solution enhanced the photolytic reaction by a factor of 6 compared to the MilliQ control. Experiments with pH adjusted OWC water also showed that when the Outlet (June) sample (low nitrate) was “spiked” with NO_3^- (to levels observed at the Inlet site) the indirect photolysis component increased to a level similar to that observed in the OWC Inlet (June) sample (Figure 6).

Effect of Daughter Products on Photodegradation: Finally, the production of 1-naphthol during the reaction may also affect carbaryl degradation. A plot of 1-Naphthol concentration versus time showed intermediate behavior and may indicate its participation in photochemical reactions. Photochemical reactivity of 1-Naphthol could influence the fate of carbaryl through a number of mechanisms. First, as this daughter product accumulates, it may compete with carbaryl or other photoreactive water constituents for photons, thereby inhibiting carbaryl degradation. Conversely, 1-naphthol may act as a photosensitizer to enhance carbaryl degradation. Control experiments were performed to test what the effect of 1-naphthol might have on the degradation of carbaryl. In phosphate buffered solutions (pH=8.5), 1-naphthol was added at various molar ratios to a solution of carbaryl (5 μ M) (Figure 7). The addition of 1-naphthol enhanced carbaryl degradation but there did not seem to be a statistical difference between the level of enhancement and the molar ratios tested. Therefore, taking the average of the results, 1-naphthol enhanced the carbaryl degradation by almost 25 percent. An important factor in determining the significance of this enhancement in natural waters will be the pH. The higher the pH, the faster the dark reaction will proceed to produce 1-naphthol which, in turn could react to degrade carbaryl.

Summary

Indirect photolytic pathways influenced the photodegradation of carbaryl in a natural wetland surface water when irradiated at $\lambda = 366$ nm. The enhancement by light appears to be related primarily to the concentration of DOC, alkalinity, and nitrate. The alkalinity of the water primarily quenched the photolytic reaction. To our knowledge this study is the first to observe that levels of nitrate actually occurring in natural water influenced the extent of the indirect photolysis of a contaminant. The amount of nitrates and nitrites present in wetlands such as OWC will be largely dependent upon the amount of agricultural runoff and municipal inputs into the system and the

degree of cycling that occurs by phytoplankton, microorganisms, and higher plants. Conceivably, nitrates in certain wetlands could be sufficiently high enough to impact contaminant photolysis if other scavengers such as carbonates and NOM concentrations are relatively small (e.g., cranberry bogs in the Northeast).

Because we chose to study the photodegradation of carbaryl at one wavelength (366 nm) present in surface sunlight, we would expect that the extent of photoenhancement would be minimized compared to that we would see in the full spectrum of sunlight. We expect that further studies conducted in sunlight will show an acceleration of the observed degradation, and are currently planned. Future research must also include the positive identification of the other daughter species besides 1-naphthol. Identification and quantification of daughter species should help to elucidate the pathways of different mechanisms. These products are also being tested for possible autocatalytic influences on the reactions. An underlying assumption of this study is that the photolysis rate is independent of pH; we are currently investigating the veracity of this assumption under these conditions.

Other results and Future Work: Atrazine showed little degradation when exposed to sunlight in quartz tubes in OWC water. A recent publication by Torrents *et al.* (1997) comprehensively examined the photochemical degradation of atrazine in a natural water spiked with nitrate (mechanisms and rates); thus we are currently restructuring our planned activities concerning this compound. The water quality parameters for ORWRP water sampled from the inlet and outlet are being characterized and will be compared to findings from OWC water. Future studies are planned to quantitate the role indirect photolysis plays in the decomposition of carbaryl, and eventually, alachlor in these different surface waters.

References:

- Aly, O.M. and M.A. El-Dib. *Water Res.* 1971a, 5, 1191-1205.
- Aly, O.M. and M.A. El-Dib. In *Organic Compounds in Aquatic Environments*, S.J. Faust, Hunter, J.V., Eds.; Marcel Dekker, INC: New York, 1971b; 469-493.
- Armbrust, K.L. and Crosby, D.G. *Pacific Science.* 1991, 45, 314-320.
- Baker D.B. *Agriculture Ecosystems and Environment.* 1993, 46, 197-215.
- Chin, Y.P.; Aiken, G.R.; O'Loughlin, E. *Environ. Sci. Technol.* 1994, 28, 1853-1858.
- Dulin, D.; Mill, T. *Environ. Sci. Technol.* 1982, 16, 815-820.
- Faust, B. C.; Hoigné, J. *Environ. Sci. Technol.* 1987, 21, 957-970.
- Gauthier, T.D.; Seitz, W. R.; Grant, C.L. *Environ. Sci. Tech.* 1987, 21, 243-.
- Gever, J.R.; Mabury, S.A.; Crosby, D.G.; *Environ. Tox. Chem.* 1996, 15, 1676-1682.
- Hwang H.; Hodson R.E.; Lee R.F. *Water Res.*, 1987, 21, 309-316.
- Larson R.A.; Zepp, R.G. *Environ. Toxicol. Chem.* 1988, 7, 265-274.

Mabury, S.A.; Crosby, D.G. In *Aquatic and Surface Photochemistry*; Helz, R., Zepp, R.G., Crosby, D.G., Eds.; Lewis: Boca Raton, FL, 1994; 149-161.

Miller G.C.; Zissok R.; Zepp R. *J. Agric. Food Chem.* **1980**, *28*, 1053-1056.

Schroeder, D.C. *J. Chromat. Sci.* **1987**, *25*, 405-408.

Torrents, A; Anderson, B.G.; Bilboulia, S.; Johnson, W.E.; Hapeman, C.J. *Environ. Sci. Technol.* **1997**, *31*, 1476-1482.

Traina, S.J. *Advanced Soil Science.* **1990**, *14*, 167-189.

Valentine, R.L.; Zepp, R.G. *Environ. Sci. Technol.* **1993**, *27*, 409-412.

Woodburn K.B.; Batzer F.; White F.H.; Schultz M. *Environ. Toxic. Chem.*, **1993**, *12*, 43-55.

Wolfe, N.L.; Zepp, R.G.; Paris, D.F. *Water Research* **1978**, *12*, 565-571.

Zepp, R.G.; Cline, D.M. *Environ. Sci. Technol.* **1977**, *11*, 359-366.

Zepp, R.G.; Hoigne, J.; Bader, H. *Environ. Sci. Technol.* **1987**, *21*, 443-450.

Publications:

1. ARTICLES TO BE PUBLISHED IN REFEREED SCIENTIFIC JOURNALS

- Miller, Penney, L., Yu-Ping Chin, 1998, Photoinduced Degradation of Carbaryl in a Wetland Surface Water, *in preparation to be submitted to Environmental Science and Technology*.
- Miller, Penney, L., Yu-Ping Chin, 1998, Mechanisms Governing the Photochemical Transformation of Carbaryl in Aqueous Systems, *in preparation to be submitted to Environmental Science and Technology*.

2. CONFERENCE PROCEEDINGS

- Miller, P.L. and Chin, Y.P. (1997) "Photoinduced Degradation of Organic Pesticides in Wetlands", *SETAC National Meeting*, San Francisco, November, 1997.
- Miller, P.L. and Chin, Y.P. (1997) "Photoinduced Degradation of Agricultural Pollutants in Wetlands", *American Chemical Society National Meeting*, San Francisco, April, 1997.
- Miller, P.L. and Chin, Y.P. (1996) "Photoinduced Degradation of Agricultural Pollutants in Wetlands", presented at the *19th Annual Midwest Environmental Chemistry Workshop*, October 12-13, West LaFayette, IN.

List of Figures

Figure 1 A map of the wetland site, Old Woman Creek State Nature Preserve (OWC). Sampling sites are labeled on the map (Inlet, Railroad, Outlet).

Figure 2 Absorption spectra for Old Woman Creek Water sampled June 17, 1996. Measured spectra vary by site. Inset #1 shows the absorption spectrum obtained for an aqueous solution of nitrate (0.74 mM), similar to the concentration measured in the 6/96 inlet water.

Figure 3 Absorption spectra for Old Woman Creek Water taken August 7, 1996. Again, measured spectra varied by site.

Figure 4 Disappearance of carbaryl (5 μ M) and appearance of 1-Naphthol in Old Woman Creek water sampled from the inlet on June 17, 1996. Data obtained from dark and light reactions have been plotted.

Figure 5 Correspondence of nitrate, DOC, carbonate to corrected (for dark reactions) rate constants

Figure 6 Comparison of corrected (for dark reactions) rate constants measured for reactions carried out in solutions of varying nitrate composition. Reactions were performed using a mercury arc lamp without light filters.

Table I. Water quality characteristics for water samples taken from Old Woman Creek (OWC) in June and August of 1996. Values in parenthesis represent %CV for replicate samples

Sample	pH ¹	DOC (mg/L)	ABS ¹ @ 366nm	ϵ @280 nm (M ⁻¹ cm ⁻¹)	S _A ²	Conductivity (μ S/cm)	Alkalinity (mM)	Nitrate (mM)
<u>Inlet</u>								
June	8.28	4.83 (3.28)	0.0282	253.2	0.964	628	3.70 (0.23)	0.47 (0.19)
August	8.28	8.56 (1.49)	0.0339	216.4	0.957	535	3.93 (0.70)	0.061 (1.29)
<u>Railroad</u>								
June	8.11	6.75 (1.37)	0.0245	206.8	0.969	589	3.55 (0.98)	0.32 (0.32)
August	8.24	11.98 (1.26)	0.0436	208.0	0.946	561	4.59 (0.50)	0.073 (0.00)
<u>Outlet</u>								
June	7.99	4.42 (2.58)	0.0106	111.3	0.986	322	2.15 (1.78)	0.13 (1.36)
August	8.14	9.01 (3.04)	0.0284	171.4	0.964	414	3.18 (0.25)	0.079 (0.00)

11

¹ pH Measured in the field. ² ABS = the Attenuation coefficient (α) since pathlength of quartz cuvettes was 1 cm. ³The screening factor can be used to quantify the effect light attenuation by natural waters will have on the direct photolysis rate. The light screening factor, S_A, can be calculated from $S_A = \frac{1 - 10^{-\alpha l}}{2.303 \alpha l}$ where l is the pathlength of the test tubes used for the experiments and α is the attenuation coefficient (simply the measured absorbance for a given wavelength when the cuvette pathlength is 1 cm)

Table II. Measured initial rate coefficients and total mass balances for the degradation of carbaryl in Old Woman Creek wetland water in the dark and light.

Sample	pH ¹	k_{obs} (hr ⁻¹)		% Mass Balance ³	Light ²	% Mass Balance ³	k_{direct} ⁴	Corrected ⁵
		Dark ²						
<u>Inlet</u>								
June	8.39	0.0607 (0.0089)		87.7	0.0827 (0.0058)	77.5	0.00329	0.0220
August	8.40	0.0675 (0.0094)		86.7	0.0771 (0.0056)	76.8	0.00327	0.0096
<u>Railroad</u>								
June	8.37	0.0563 (0.0086)		94.1	0.0702 (0.0053)	73.0	0.00331	0.0139
August	8.46	0.0796 (0.0106)		78.8	0.0836 (0.0059)	77.8	0.00323	0.0040
<u>Outlet</u>								
June	8.15	0.0407 (0.0083)		93.9	0.0391 (0.0045)	90.1	0.00337	N/A ⁶
August	8.34	0.0639 (0.0095)		96.2	0.0549 (0.0050)	80.3	0.00329	N/A ⁶

¹ Values represent the average pH measured throughout the course of the reaction ² Values in parenthesis represent the 95% confidence level.

³ Calculated as the sum of all quantifiable species measured at the time 1-naphthol formation reached its maximum concentration, divided by initial carbaryl concentration. ⁴ Values predicted from $S_{\lambda} \times k_{direct}$ measured in distilled water. ⁵ Rate constants were corrected for the dark reactions.

⁶ Corrected rate constants were not calculated since there was no apparent photochemical enhancement of carbaryl degradation in these samples.

Figure 1 A map of the wetland site, Old Woman Creek State Nature Preserve (OWC). Sampling sites are labeled on the map (Inlet, Railroad, Outlet)

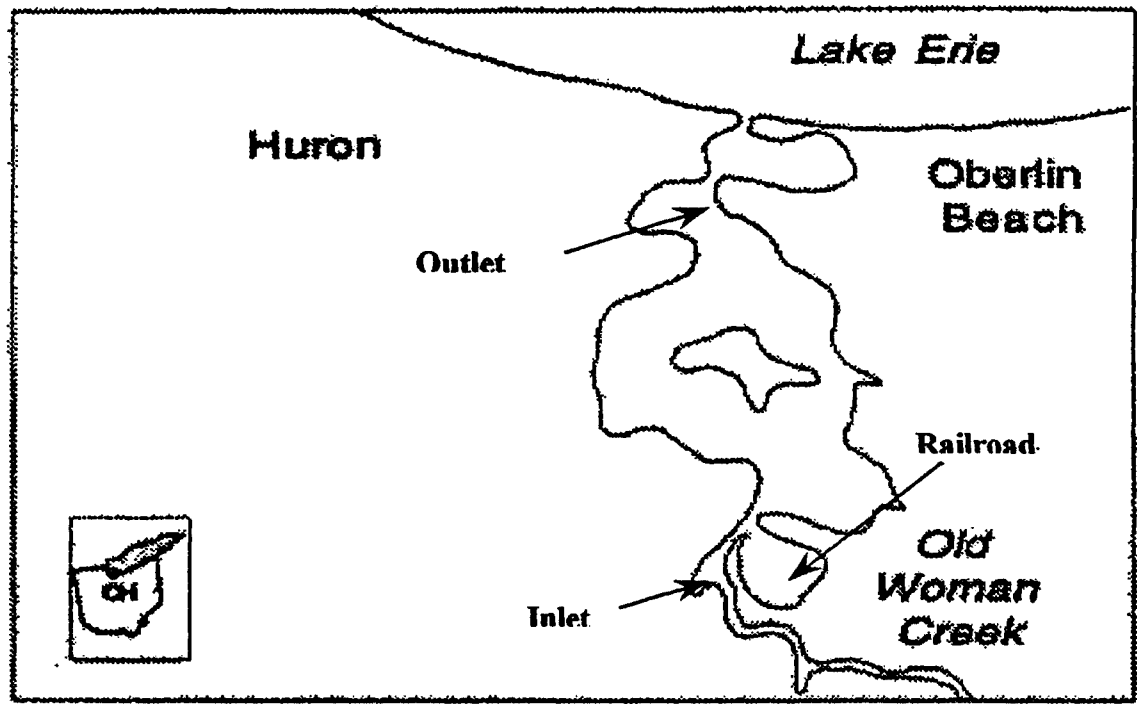


Figure 2 Absorption spectra for Old Woman Creek Water sampled June 17, 1996. Measured spectra vary by site. Inset #1 shows the absorption spectrum obtained for an aqueous solution of nitrate (0.74 mM), similar to the concentration measured in the 6/96 inlet water.

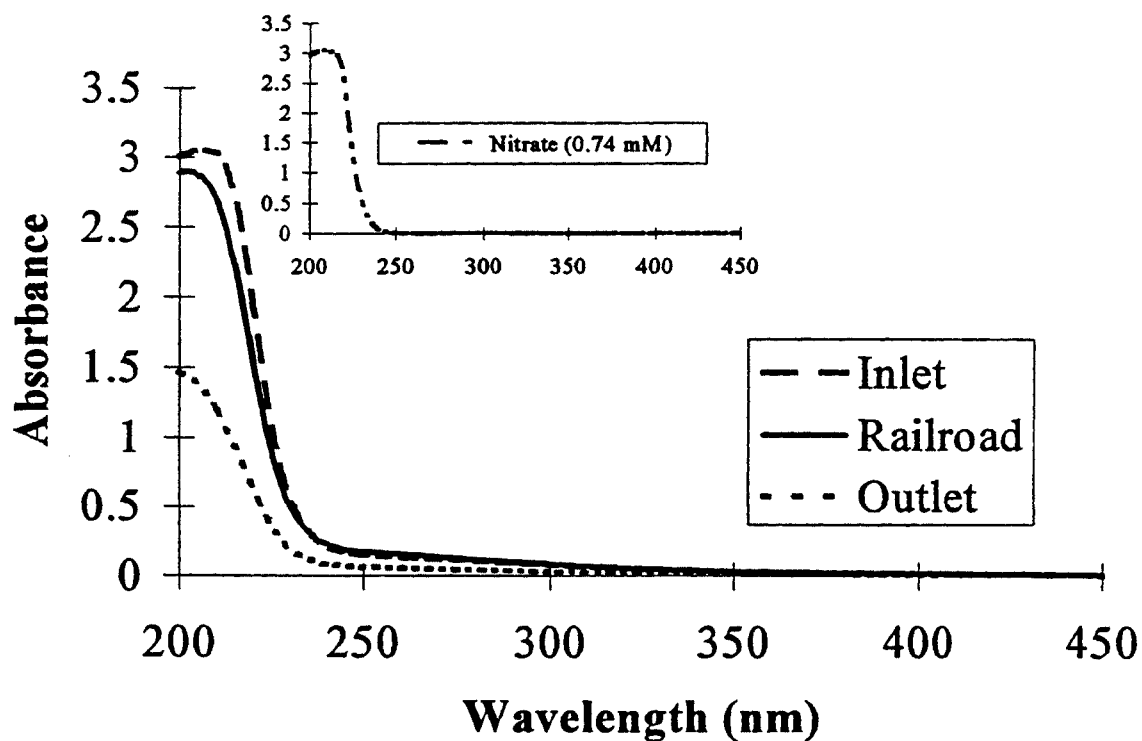


Figure 3 Absorption spectra for Old Woman Creek Water sampled August 7, 1996. Again, measured spectra varied by site.

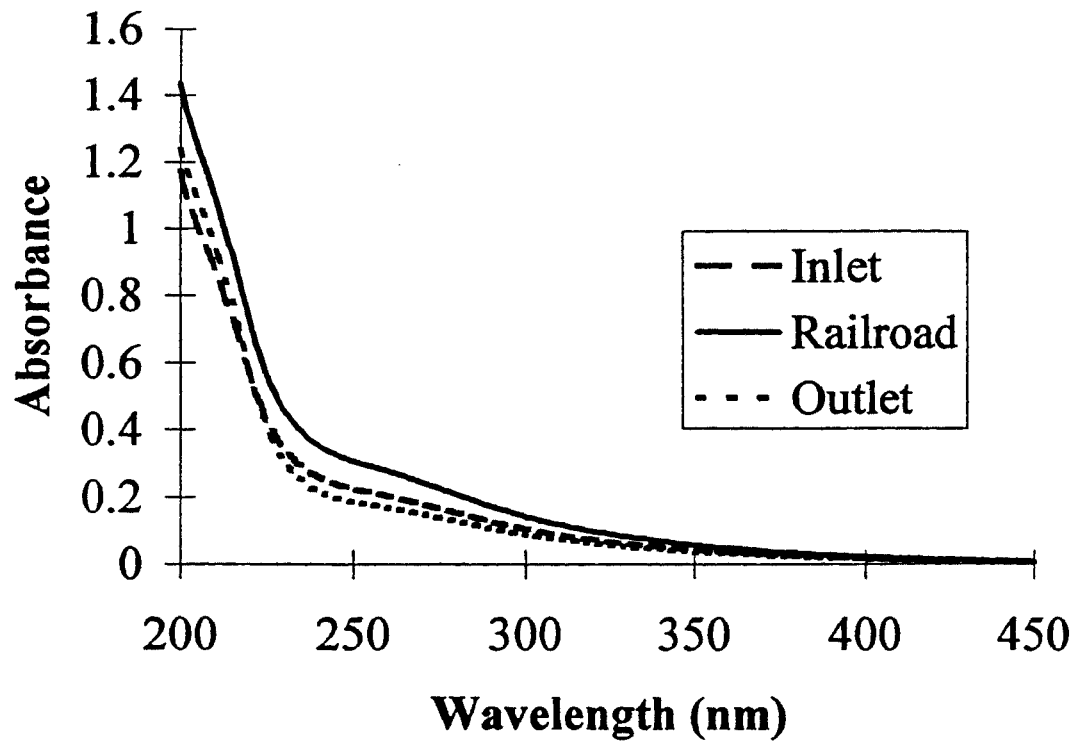


Figure 4 Disappearance of carbaryl (5 μM) and appearance of 1-Naphthol in Old Woman Creek water sampled from the inlet on June 17, 1996. Data obtained from dark and light reactions have been plotted.

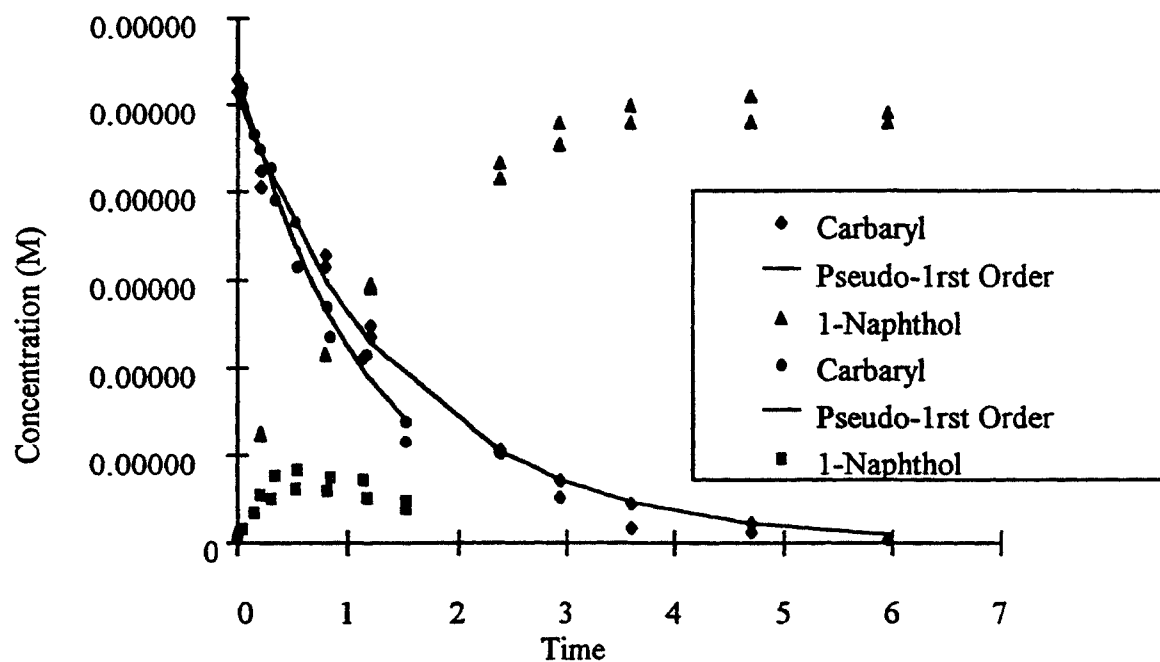


Figure 5 Correspondence of nitrate, DOC, and carbonate to corrected (for dark reactions) rate constants.

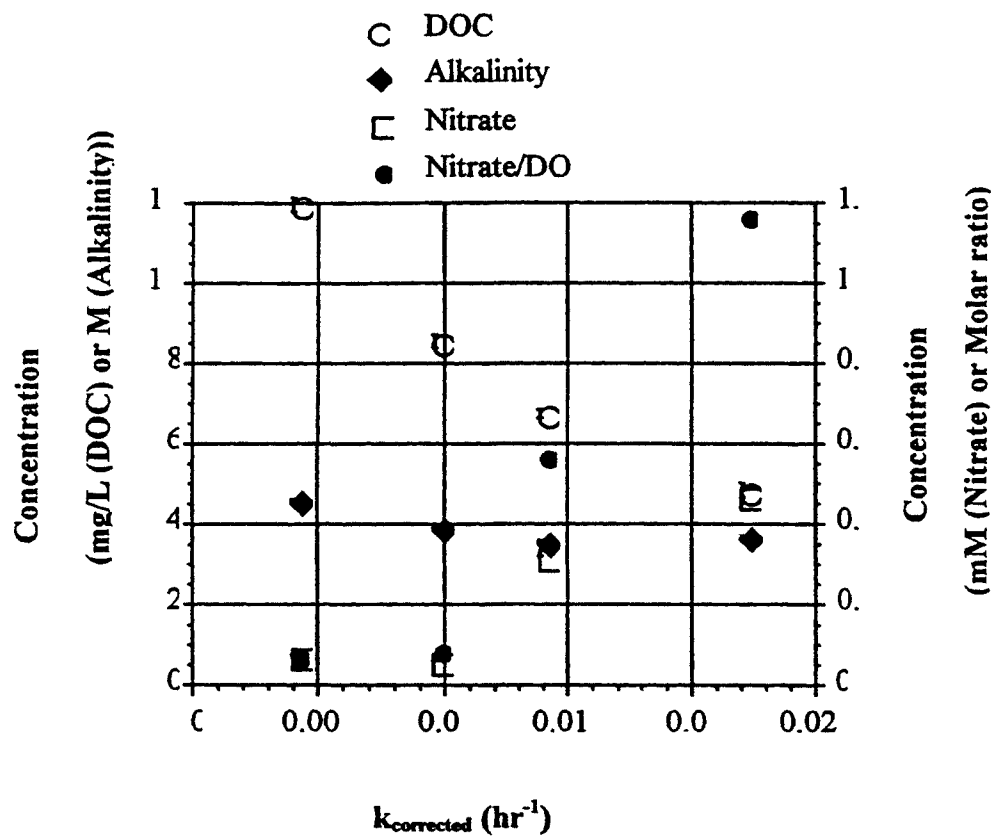


Figure 6 Comparison of corrected (for dark reactions) rate constants measured for reactions carried out in solutions of varying nitrate composition. Reactions were performed using a mercury arc lamp without light filters

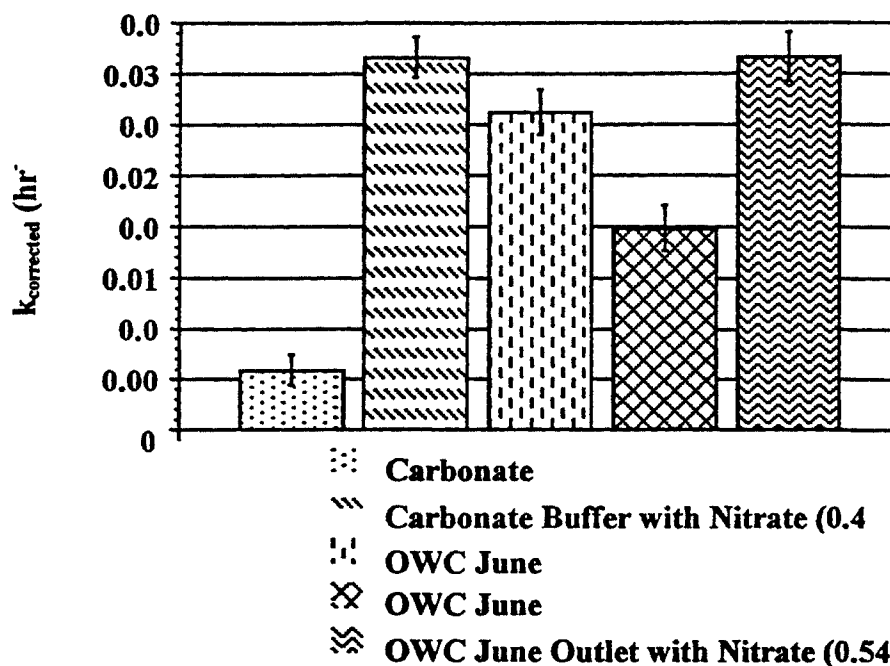
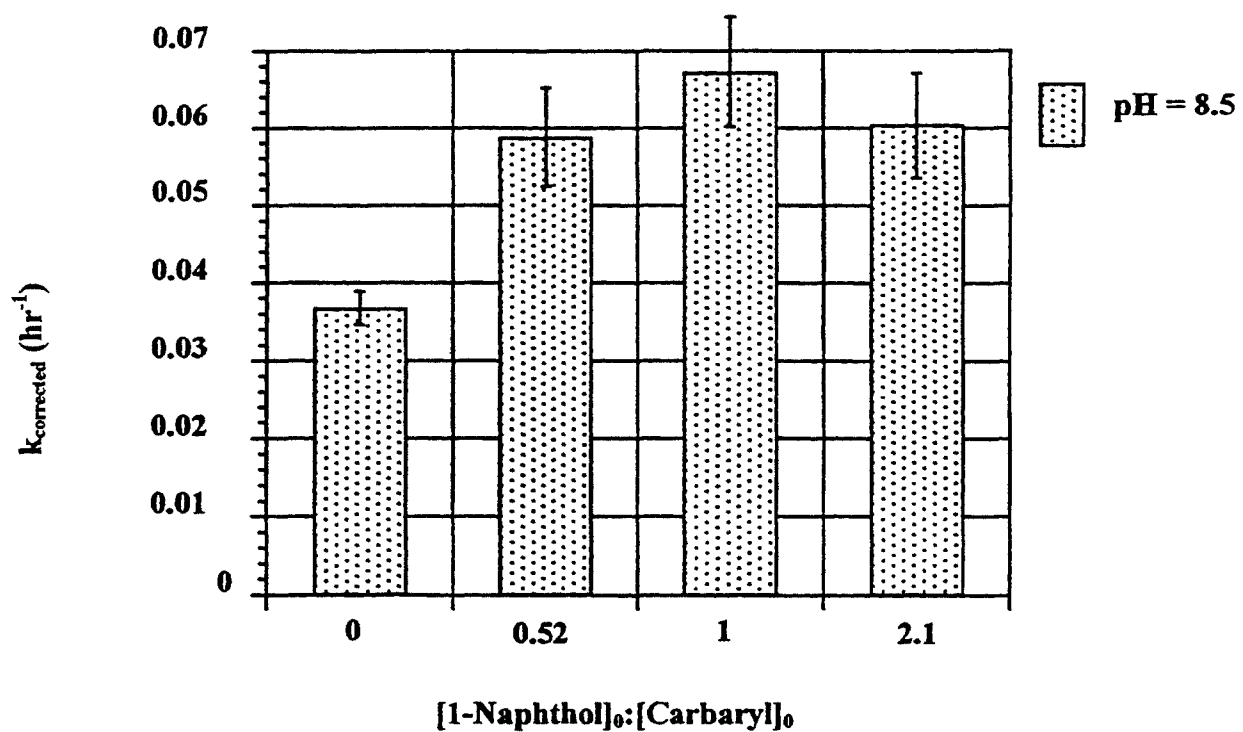


Figure 7 The effect of 1-Naphthalol on the measured rate constant (corrected for the dark reaction) for the photodegradation of carbaryl.



SYNOPSIS

Project Number: C-03

Start: October, 1997
End: December 1999

Title: Economic and Hydrologic Analysis of Integrated Wetland Reservoir and Subirrigated Agricultural Production Systems

Investigators:

Larry C. Brown, The Ohio State University
Marvin T. Batte, The Ohio State University

Congressional District: Fifteenth

Focus Categories: WL, HYDROL, ECON

Descriptors: Constructed wetlands, subirrigation, hydrology, agriculture, economics, water table management, water level and quality control, water harvesting and conservation, solute transport, ecosystems, agroecosystems, education, hydraulics, drainage management, impoundments, information dissemination, irrigation and management, land-water interactions, perched water table, ponds, reservoir development and management, sedimentology, storm water management, nutrient delivery to streams, sediment, runoff, subsurface drainage, surface drainage, controlled drainage, near-surface ground-water levels, hydrologic and ecosystem models, Great Lakes, water reuse and recycling, landscape and watershed management, off-site impacts, management, modeling, and monitoring, water resources development, water use monitoring.

Problem and research objectives:

The Maumee River valley is characterized by flat topography with soils that are predominantly heavy clay - glacial deposits and lakebed sediments. Extensive drainage projects have permitted the area to be drained, cleared, and farmed, resulting in a very productive farming region, but one which is very dependent on surface and subsurface drainage improvements. Drainage discharge enters the Maumee River and Lake Erie as a result of intensive drainage improvements. Sediment, phosphorus, nitrate, and certain pesticides in agricultural runoff are of great concern in the region. No research has been conducted on hydrologic interactions within the direct linkage of an agricultural production system and a wetland-reservoir ecological system, nor the economics of such a system.

An existing demonstration project (funded by USEPA/GLPO and others) demonstrates construction and management of permanent wetland-reservoirs linked directly to subirrigated corn and soybean production systems on field-sized areas. The demonstration project was initiated in 1994 to illustrate how construction and management of wetlands coupled with subirrigation can be economically profitable for farmers. The overall objective of the demonstration project is to

stimulate adoption of wetlands, reduce adverse impacts of agricultural runoff, and maintain profitability. The project was built on the need to enhance and properly utilize wetlands near agricultural land use areas where the success of subirrigation has a high potential.

The WRRI project adds important economic and hydrologic research components to the existing Maumee River valley demonstration project. This productive farming region is very dependent upon drainage improvements, which discharge to the Maumee River and Lake Erie where sediment, phosphorus, nitrate, certain pesticides in runoff are of concern. Runoff and drainage from prior converted cropland will seasonally feed wetland-reservoirs, which provide water quality and wildlife habitat functions, and supplemental water supply for state-of-the-art subirrigated crop production systems. Construction and management phases for three wetland-reservoir-subirrigation sites are funded (operational for 1996 growing season) and complete. Research was needed on hydrologic interactions within the direct linkage of agricultural production systems and wetland-reservoir ecological systems, and the economics of such systems. Currently, no work of this focus and extent is being conducted elsewhere in the U.S.

Research Objectives

Objective 1: Characterize, analyze, model hydrologic interactions between integrated subirrigated agricultural production and constructed wetland-reservoir systems, and evaluate the water quality (sediment, pesticide, nitrate and phosphorus transport) impacts and benefits of this integrated system.

Objective 2: Examine and determine farm-level economics of integrated subirrigated agricultural production and constructed wetland-reservoir systems.

Technology Transfer Objective

Objective 3: Develop a technical design and management guide for subirrigated agricultural production and constructed wetland-reservoir systems, and conduct an applications and design workshop to teach agricultural producers and consultants how to use water table management for environmental and economic benefit.

Methodology:

Existing Funded Demonstration Project

Wetlands have been constructed on prior-converted cropland to receive drainage from adjacent cropland, resulting in zero-discharge from those fields directly to streams. Agricultural runoff and subsurface drainage will recharge the constructed wetland seasonally during periods. The wetland-reservoir water will be recycled through a subirrigation system, thereby providing a supplemental water supply for subirrigating corn and soybean crops in adjacent fields. In a year with average rainfall, the system should produce a zero discharge to streams and rivers which will

greatly aid in improving water quality, reducing peak flows, and at the same time form permanent pools for increased wildlife habitat areas. Substantial subirrigation research on corn and soybean conducted in Michigan and Ohio suggests a strong potential for northwestern Ohio, but often water supply is a limiting factor.

The soils and topography are those that will respond to subsurface drainage improvement, subirrigation, and constructed wetlands. Cropping and management plans for the entire farm include agricultural practices used in accordance with an approved conservation plan as prepared by USDA-NRCS, with a landowner commitment of five years minimum. Each landowner is required to provide information on all inputs and outputs, and follow the water management plan and the cropping management plan established by the project team (contract established between demonstration project and landowner).

The systems were designed using research results and inputs from the USDA-ARS Soil Drainage Research Unit; Michigan State University - Department of Agricultural Engineering; The Ohio State University, Department of Food, Agricultural, and Biological Engineering, Ohio Agricultural Research and Development Center, and Ohio State University Extension; and technical assistance from the USDA-NRCS and the Ohio and Michigan Land Improvement Contractors' associations. The Maumee Valley RC&D coordinates all specific tasks with the main sponsors (USEPA/GLPO; Lake Erie Protection Fund, etc.), and all collaborators.

The WRRI funded research focuses on all 3 sites: Defiance Agricultural Research Association (DARA) site (near Defiance County airport and weather station); Fred Shiningher farm (Fulton County); and March Foundation (Van Wert County near Farm Focus), but the main focus of the intensive monitoring and research is at the DARA site. Each site consists of a subirrigated area for corn and soybean production, constructed wetland, and constructed upground reservoir (or existing pond). Runoff and subsurface discharges from adjacent cropland flows into the constructed wetland. Once water flows out of the wetland, it is pumped to the upground reservoir where it is stored for water supply. During the crop season, water is pumped into the subirrigated cropland, where a water table is held at a 14- to 20-inch depth throughout most of the growing season. Each site will have numerous locations to measure and sample surface and subsurface flows, subirrigation water use, runoff, etc., and are being instrumented so that water flow rates and volumes, and sediment and chemicals concentrations can be measured at the inflow and outflow of each component of this integrated system.

Runoff and subsurface discharge will be monitored and evaluated during and after all storm events (possibly 10 to 20 storm events annually), and during selected less dynamic times throughout the year. One-liter water samples will be collected during flow events. For two selected storm events per year, more intensive sampling will occur to establish the water and chemical discharge relationship with time for the entire rainfall event. All samples will be analyzed for nitrate+nitrite, soluble phosphorus, and selected pesticide concentrations by the Water Quality Laboratory at Heidelberg College in Tiffin, Ohio, and the MSEA Water Quality Lab at Ohio State University following MSEA QA/QC procedures. All concentration data will be analyzed on a flow-weighted

basis. For the recessional limb sampling, the number of samples collected each year will be approximately 90 (up to 20 events per year, at up to six sampling locations). For the full storm duration sampling sequence, approximately 80 samples will be collected per year (20 samples per selected storm event per year for both drainage treatments). Sediment samples will be analyzed locally by gravimetric means. Wetland and reservoir sedimentation will be assessed annually.

Inflows and outflows from each flow control point will be measured at time of sampling. In addition to the installation of commercial flow rate and volume measurement devices, the drainage control structures will be modified with a V-notch weir for flow rate estimation at the time of sampling, thus producing a redundant volumetric sampling. Runoff entering the wetland area will be monitored using H-flume and stage recorder systems. Within each field area, simple water table observation wells will be installed between laterals near each outlet to allow monitoring of water table elevations. Rainfall at each site will be measured using manually read rain gauges, and local weather records are available in each county. Daily measurements of water table elevations, flow rates and volumes, etc. will be made by the demonstration project personnel.

All management and data collection at all three sites is fully funded through the existing project through the 1999 crop season, and is managed by a team of farmers, state and federal agency personnel, and university faculty. All instrumentation and data collection procedures are being designed by Dr. Brown, in coordination with the demonstration project team. Each site has unique characteristics that allow excellent research opportunities over a range of conditions.

Objective 1: Characterize, analyze, model hydrologic interactions between integrated subirrigated agricultural production and constructed wetland-reservoir systems, and evaluate the water quality (sediment, pesticide, nitrate and phosphorus transport) impacts and benefits of this integrated system.

Substantial soils, topographic, cropping system, water budget, sediment and chemical data, and engineering design information, will be generated from the existing demonstration project. Much of this information and data will be used to calibrate existing, state-of-the-art agricultural water management models and design techniques that will be modified to analyze and evaluate hydrologic interactions between these systems (discussed below).

Soil characteristics (profile description, textural analysis, hydraulic conductivity, etc.) will be measured at each site. In addition, each field-sized research area were hydraulically characterized before the actual design, construction and implementation of subirrigation. All crop production and land management conditions will be the same on both the subirrigated and non-subirrigated areas. Crop growth and production characteristics (leaf area index, height, canopy, yield, etc.) will be measured during each crop season. Crop yield, crop production management, tillage, and nutrient and pesticide application data will be collected from each cooperator. A water table management scenario will be established at each demonstration site in consultation with the demonstration project technical advisory committee, and based upon recommendations by Cooper and Fausey (1991; 1992).

Dr. Brown and the engineering graduate associate will conduct the research that addresses Objective 1 using the agricultural water management simulation models DRAINMOD (Skaggs 1980; Skaggs et al. 1981), ADAPT (Agricultural Drainage and Pesticide Transport) (Chung et al. 1992a; Chung et al. 1992b), and possibly the new USDA erosion model WEPP (Water Erosion Prediction Project). These hydrologic and erosion prediction models will be used to conduct computer simulations using long-term climatic records to evaluate the hydrologic and crop production potential of the soils at all three demonstration sites for subirrigation and drainage collection in the study area. These hydrologic models have the ability to evaluate subirrigation scenarios, and can be used to analyze and evaluate these integrated systems over time using historic climatic records. Both DRAINMOD and ADAPT have the capability to simulate water table elevations, surface and subsurface movement of water on agricultural soils that are not drained, and for water table management conditions with conventional subsurface drainage, controlled drainage, and subirrigation. Long-term subsurface discharge, runoff, evapotranspiration, water use, water table elevation, and other water budget parameter estimates, as well as crop yields, will be statistically evaluated. In addition, sediment, pesticide, nitrate and phosphorus movement from all three sites will be evaluated using the ADAPT model.

For use with DRAINMOD and ADAPT, soils data have been obtained at each site, from the state's Soils5 data base (Baumer, 1989), and county soil survey manuals. In addition, hydraulic conductivity and topographic information from each demonstration site has been obtained for our use. Climatic data (hourly precipitation, max/min daily temperatures) with a minimum of 30 years of record (forty year records are being developed) for at least four northwest Ohio locations have been obtained and formatted for DRAINMOD. These records will be modified for input to ADAPT so that each model will use the same soils and climatic data

The DRAINMOD and ADAPT models produce similar predictions of water table elevations on agricultural land use areas (Desmond et al. 1994), and both models have been tested on Ohio conditions. DRAINMOD currently does not have the capability to predict water quality impacts (sediment, nitrate, phosphorus, pesticide transport). However, the ADAPT model has the capability to model erosion processes, and based upon algorithms adapted from the GLEAMS model (Knisel et al. 1992), it can model nitrate and phosphorus transformations and transport. ADAPT will be used in this study to assess the hydrologic, erosion, runoff, subsurface drainage, and crop yield potential of water table management practices for the demonstration site soils. Because of its wider acceptance throughout the United States to evaluate the hydrology of agricultural land use areas and wetland hydrology, DRAINMOD predictions will be used simultaneous to ADAPT as a control. For the conditions at each demonstration site, long-term simulations will be used to develop matrices of crop yield, nitrate and phosphorus transport relationships, thus allowing the research team to assess the relationship of the economic and water quality benefits of these integrated subirrigated - constructed wetland-reservoir systems.

The USDA erosion model WEPP (Water Erosion Prediction Project) is being evaluated for its application to this project..

Objective 2: Examine and determine farm-level economics of integrated subirrigated agricultural production and constructed wetland-reservoir systems.

The long-term economic performance of integrated subirrigated agricultural production and wetland-reservoir systems investments relative to systems with no subirrigation-wetland linkage will be analyzed and evaluated. Net present value techniques will be used to value profitability, and linear programming techniques will be used to compare differences in profitability reflecting differences in farm size under the two production systems. Actual capital investments for design and construction will be obtained from each demonstration site. Estimates of the useful life of each component of the system and maintenance costs will be made, and actual production costs, yields, and returns will be collected for production of each crop at each site. Historical yield and cost data will be gathered for each site for years prior to the wetlands development. These data will be the basis for comparison of economic costs and returns for each site, prior and subsequent to the wetlands-subirrigation investment. In addition, Drs. Fausey and Cooper, and the Michigan State cooperator, respectively, have agreed to provide selected Ohio and Michigan water table management system cost and return economic data. For comparison, we are currently evaluating the subsurface drainage yield response data from two long-term projects in Ohio.

Dr. Batte and the Agricultural Economics' graduate associate will assess the economic performance of subirrigation technologies. Enterprise and whole-farm budgeting techniques will be used to examine the impact of the subirrigation investment for typical Ohio commercial farms. Because these investments involve long-time durations, capital budgeting techniques also will be used to reflect differences in timing of receipts and expenditures. Additionally, mathematical programming techniques will be used to compare the economic performance of a representative farm with and without subirrigation improvements. Enterprise and whole-farm budgets will be constructed for representative farms under two scenarios: 1) with a conventional subsurface drainage system designed to be optimal for prevailing soil conditions, and 2) with a subirrigation system, again designed to be optimal given existing soils.

Simple budgeting analyses as described above and reported in a number of empirical studies (Evans et al. 1988; Rath and DeBoer 1991; Belcher 1992; and Drouet et al. 1989) do not provide a complete analysis of profitability differences among systems. The reason is that there may be changes in a great number of other aspects of the business resulting from the subirrigation investment. Positive impacts may include farming of larger acreage, incorporation of higher-valued (but previously infeasible) crops into the rotation, greater specialization in the highest-valued crop, or reduced hiring of labor during critical periods for field operations. Negative impacts might include increased competition within the business for scarce capital resources and associated loss of production efficiency or business size.

Linear programming models will be constructed for representative farms in northwestern Ohio. At each site, one model will feature crop production on representative soils with conventional

subsurface drainage. A second model will consider the addition of a subirrigation system that will provide supplemental subsurface irrigation as well as provide improved drainage. The owned land base and the existing machinery complement will be treated as fixed resources. Decision variables will include farm size (expandable through leased acreage), crop rotation, and other cultural practices. The model will incorporate constraints on capital, labor, and machinery capacity which are functions of both weather and drainage system during several planting and harvesting periods.

In order to understand the impact of water quality guidelines imposed on the farm firm, the base model will be modified to incorporate externally imposed constraints (pollution limits) on nitrate and phosphorus discharge. Previous studies have demonstrated that subirrigation systems have the potential to reduce the level of nutrient discharge from subsurface drains (Wright et al. 1992).

In order to meet water quality guidelines, farms with conventional subsurface drainage systems will need to make greater changes in the overall organization of their farming system (e.g., reduced fertility rates, change of rotation, and/or adoption of other pollution abatement practices) than will a similar farm with subirrigation. Such alterations may significantly impact profitability.

The linear programming model will be constructed in such a way as to allow measurement of the sensitivity of the crop production activities in the optimal solution to prices of key resources, prices of commodities, and restrictions on labor or capital availability. Standard linear programming output provides estimates of the marginal value of additional resources as well as an indication of the amount by which profitability of competing activities must change before those activities would enter the optimal farm plan.

Objective 3: Develop a technical design and management guide for subirrigated agricultural production and constructed wetland-reservoir systems, and conduct an applications and design workshop to teach agricultural producers and consultants how to use water table management for environmental and economic benefit.

Technology transfer is a major component of both the existing demonstration project and the proposed project, using tri-state (Ohio, Indiana and Michigan) water management conferences and field days to teach farmers, technical and regulatory agency personnel, and non-agricultural citizens the benefits of interfacing wetlands with modern agricultural production.

Research/demonstration results will be the basis for management guide development, with a primary focus on environmental and economic benefits of water table management and constructed wetlands, site identification, water supply, engineering design, construction, and system operation and management. All aspects of the existing demonstration project and proposed project will feed into Dr. Brown's educational activities conducted cooperatively by Ohio State University Extension, the demonstration project and its cooperators and technical advisors, and the Overholt Drainage Education and Research Program at The Ohio State University.

The state-of-the-art knowledge of water table management and associated constructed wetlands technologies will be developed into a comprehensive technical and educational guide on the

design, operation and management of subirrigation systems that enhance water quality and sustain productivity. Research from across the Cornbelt, Great Lakes, and southeast regions of the U.S., and from Canada will be incorporated into this effort. Computer simulation models (i.e., DRAINMOD, ADAPT), and the subirrigation evaluation/design model SI-DESIGN (Belcher et al. 1993) will be used in the analysis. The results of the analyses performed to address Objectives 1 and 2 will be incorporated into this effort. Dr. Brown will conduct a series of one- to two-day planning sessions to outline the content and production schedule for the guide. The guide content will be produced by the end of year two of the project.

Field demonstrations of research is an excellent mechanism through which agricultural producers can be educated. This technology transfer technique actually incorporates complex research systems into field teaching laboratories. Field demonstration days will be organized and conducted at selected demonstration sites each year of the proposed project. Field demonstration days will be conducted in a cooperative effort by the Maumee Valley RC&D, Ohio State University Extension, and Drs. Brown and Fausey. These field demonstration days will be advertised in the Great Lakes Region. Field day participants will witness field-scale and plot-scale subirrigation, constructed wetlands on prior-converted cropland, be exposed to the operational requirements for successful subirrigation and management of a constructed wetland-reservoir, and be presented with data that supports the economic and water quality benefits of water table management by subirrigation integrated with constructed wetland-reservoirs.

The project team will conduct one regional workshop in year two of the proposed project. This will be an multi-disciplinary, interagency effort, primarily targeting agricultural producers. However, persons who provide agricultural water management services to producers will be targeted as a secondary audience (technical agency personnel, soil and water conservation contractors, consultants, etc.).

Progress report:

Wetland-Reservoir-Subirrigation Systems (WRSIS) have the potential both to improve downstream water quality by reducing discharge to streams, to provide wildlife habitat, to increase wetland acres and vegetation, and to provide a reliable supply of subirrigation water for sustained crop production. In a WRSIS, a wetland is constructed to receive subsurface drainage and runoff from adjacent cropland. The cropland is subirrigated by a water supply reservoir which is also linked to the constructed wetland. The wetland, reservoir and subirrigated cropland are integrated to recycle runoff and drainage waters.

Prior to WRRI funding, three constructed wetlands were designed, constructed, and linked with water supply reservoirs for corn and soybean production systems using subirrigation. All three systems, located in the Ohio portion of the Maumee River Basin, were operational in the 1997 growing season, and provided yield data. The wetlands were constructed on prior-converted cropland (soils dominantly silty clay and clay) to receive drainage from adjacent cropland, resulting potentially in zero-discharge from cropland directly to streams, except during extreme

precipitation events. Agricultural runoff and subsurface drainage recharge the wetland seasonally, and the reservoir serves as a supplemental water supply source for subirrigating corn and soybean. The constructed wetlands, primarily designed to serve as runoff and drainage collection and detention components, have developed wetland vegetation. A comprehensive wetland vegetation survey was undertaken in May 1998.

Non-replicated yield data, averaged over four varieties of both corn and soybean, for 1996 (first year of study) from the Fulton County site indicated a yield increase for both corn and soybean of approximately 50% for subirrigated versus conventionally drained cropland. The 1996 growing season had normal-to-below normal rainfall. The crop yield data from 1997 indicate no difference between the subirrigated systems and the conventional drainage system. These data suggest that the system benefited from the more intensive drainage spacing with the subirrigated system compared to conventional drainage. The growing season had above normal precipitation, and a fairly uniform rainfall distribution.

A comprehensive monitoring system has been designed for the Defiance County site to collect a large variety of data useful for hydrologists, biologists, wetland ecologists, modelers and decision support system designers, engineers, and natural resources conservationists. This system should be installed and operational by August or September 1998. A summary of individual subprojects within the overall research scope follows.

Monitoring System for Water Quality and Quantity, and Ecological Parameters at the DARA Wetland-Reservoir Subirrigation System Site. At the Defiance Agricultural Research Association (DARA) site in Defiance, Ohio, an intensive monitoring program has been implemented in order to monitor and analyze the performance of the system. Instrumentation is being installed to measure system parameters necessary to fully evaluate the benefits, operation and management, and economics of the system and its components. Hydrological, agricultural, environmental, and ecological focus areas include: determination of system water balance; water routing for water conveyance, storage and water supply; subirrigation water requirements for corn and soybean production; operation and management of system components; farm-level economics; sediment routing and trapping; nutrient and pesticide fate and transport; plant community development and diversity, wetland vegetation, and vegetative habitat for wildlife; macro-invertebrate community development; net water, sediment, nutrient, and pesticide losses off-site. The ecological impact of the system is also being analyzed through the monitoring of the diversity of the vegetative growth in and around the wetland and the monitoring of aquatic macro-invertebrates within the wetland. A paper is being prepared for presentation at an international professional meeting in 1998.

Water Column Sampling System for the Constructed Wetland and Water Supply Reservoir at the DARA WRSIS Site. In the WRSIS system, the wetland, reservoir and subirrigated cropland are integrated to collect and recycle runoff and drainage waters from cropland. Three systems have been developed, and the DARA site is being instrumented with a water column water sampling system to evaluate water quality parameters in the wetland and reservoir. A prototype sampling system has been designed and constructed. Two systems are being constructed for installation so

that drawdown conditions can be sampled before the crop season. The background, design, construction, and installation of the system are being evaluated, with the expectation to install revisions of this sampling system at the other two sites in late 1998 or 1999. A paper is being prepared for presentation at an international professional meeting in 1998.

Modeling of Water Routing in a Wetland-Reservoir-Subirrigation System Using SIMULINK.

WRSIS have the potential both to improve downstream water quality by reducing discharge to streams and to provide a reliable supply of subirrigation water. In order to help evaluate the performance of such systems, a model is being developed to simulate the routing of water between the system's components and to model the water balance within each of the components.

This work is being done using SIMULINK, a software package which uses block diagrams to define dynamic systems. In the model, an entire library of blocks representing each of the different components of the system (i.e., wetland, subirrigated field, pump station, reservoir, etc.) can be developed. Each of these blocks actually represents a sub-system of blocks that model the dynamic behavior of that component. The system component blocks can be linked to model a wide range of system configurations for WRSIS sites. The model can also be used to analyze a variety of different management strategies. Once the model is developed, calibrated and tested at the DARA site, it will be evaluated at the two other demonstration sites. Future development will focus on automatic system operation and optimization, and real-world implementation. A paper is being prepared for presentation at an international professional meeting in 1998.

Modeling of Water and Sediment Routing in a Wetland-Reservoir-Subirrigation System Using the WEPP Watershed Model. In addition to the modeling work above, we are currently modifying and evaluating the WEPP Watershed model, which contains a hydrologic elements, impoundments, and routing routines for water and sediment. We are modifying the model to incorporate a more robust water table management component to handle subirrigated and drainage controlled landscapes. We are currently evaluating the subsurface drainage component against data from a previous northwest Ohio study.

Evaluation of Long-term Yield Data on Subsurface Drainage Few historic drainage response studies have been conducted in the U.S. and Canada. Ohio, however, is home to two such studies that provide yield results valuable for assessing the economics of drainage improvement on agricultural soils. Long-term studies on Toledo clay (20+ years) and Hoytville silty clay (12+ years) in northcentral and northwestern Ohio, respectively, have been conducted to evaluate the effects of drainage, rotation, and tillage on corn and soybean yield on clay soils. These studies were designed to help researchers and producers understand how to increase and sustain crop yields, and maximize profits in corn and soybean production while incorporating sound conservation practices. The study on Toledo clay was conducted from 1958 through 1982 in Sandusky County, Ohio, by G.O. Schwab. The Hoytville silty clay study was conducted from 1984 through 1996 in Wood County, Ohio. Results from both of these studies indicated that subsurface drainage substantially improved average corn and soybean yields, and that drainage improvement helps reduce the year-to-year variability in yields. In some cases, surface drainage improvements were a better option compared to only subsurface drainage. Benefit/Cost analyses

conducted for the Wood County site provides B/C ratios ranging from 1.7 to 3:1. These data will be used as the baseline for yield response for comparison to the yield data from the wetland-reservoir subirrigation systems.

Farm Level Economics and Capital Costs Analysis of Three Wetland-Reservoir Subirrigation System Sites in Northwestern Ohio. The construction all three sites was completed in 1996 and 1997. Construction and all other capital costs were documented and are being analyzed. A survey of drainage and land improvement contractors has been implemented to ascertain local construction cost information (average costs and ranges) for different system components (design, site preparation, wetland, reservoir, subirrigation, pumping plant, drainage, waterways, etc.) to compare to the costs data for these three systems. Yield data from the first two years of this project and from subirrigation research plots from other locations in Ohio and Michigan, will be used to analyze the benefits of these systems for improved and sustained crop production. Yield data from several long-term crop yield studies with conventional subsurface drainage are being analyzed for use in comparisons with the WRSIS yield results. The overall analysis of these costs will be used to provide to farmers information for use in evaluating their application of the technology. A paper is being prepared for presentation at an international professional meeting in 1998.

The project enjoys great interdisciplinary, multi-agency, and stakeholder participation. The overall project is a cooperative team effort between the Maumee Valley RC&D (MVRC&D), USDA-Natural Resources Conservation Service (NRCS), USDA-Agricultural Research Service (ARS) Soil Drainage Research Unit, The Ohio State University (OSU), Michigan State University (MSU), Heidelberg College (HC), Soil and Water Conservation Districts (SWCD), farm cooperators and county commissioners, Ohio and Michigan Land Improvement Contractors (O&MLICA), Drainage Products Industry (ADS, Hancor, Haviland, Baughman), with recent collaboration with ODNR Division of Wildlife (SW), USF&WS, USACOE, and other local and state agencies and organizations.

The overall project funding is provided, in part, by USEPA GLNPO; Lake Erie Protection Fund; OARDC and OSU Extension; Ohio Sea Grant College Program; USGS Water Resources Competitive Grants Program; Water Resources Center, The Ohio State University; USDA-ARS Soil Drainage Research Unit; USDA-CSREES Hatch Proj. 965; Overholt Drainage Education and Research Program, Dept. Food, Agric., and Biol. Engr., The Ohio State University; and the cooperating landowners, agencies and organizations.

This innovative, ecologically sound crop production system will recycle runoff and drainage waters, reduce runoff, sediment, and agricultural chemical discharges to streams, improve water quality, increase wildlife habitat, increase wetland acres, and enhance farm profitability. The demonstration project team (farmers, state and federal agency personnel, university faculty) will provide high level input to proposed research and help evaluate application of results to users.

Integrated research and demonstration efforts will produce a management guide with focus on environmental and economic benefits, site identification, water supply, engineering design, construction, and system operation and management.

References

- Baumer, O.W. 1989. SCS Soil Parameters Preparation Program for DRAINMOD. DMSOIL User's Manual. USDA-Soil Conservation Service, National Soil Survey Laboratory, Lincoln, NE. 24 pp.
- Belcher, H.W., G.E. Merva and W.H. Shayya. 1993. SI-DESIGN: A simulation model to assist with the design of subirrigation systems. IN:Proceedings of the ICID Workshop on Subsurface Drainage Simulation Models. The Hague. September 4 and 5, 1993, pp. 295-308.
- Breve M.A., R.W. Skaggs, H. Kandil, J.E. Parsons and J.W. Gilliam. 1992. DRAINMOD-N: A nitrogen model for artificially drained soils. IN:Proceedings of the Sixth International Drainage Symposium. ASAE. St. Joseph, MI. Publication No. 13-92:327-336.
- Brown, L.C. and P. Bierman. 1994. Water management strategies for balancing sustained crop production and water resource protection. State Project. Ohio Agricultural Research and Development Center. Ohio State University.
- Brown, L.C., E.J. Kladvko and R.F. Turco. 1994. Subsurface drainage impacts on agricultural chemical movement to ground and surface water. In: A.S. Felsot, J.J. Jenkins and N.N. Ragsdale (editors). Pesticide Management: Minimizing Environmental Impacts. Lewis Publishers. (In review).
- Chung, S.O., A.D. Ward, N.R. Fausey, W.G. Knisel and T.J. Logan. 1992a. An evaluation of the ADAPT water table management model. IN:Proceedings Sixth International Drainage Symposium. ASAE Publication No. 13-92:337-344.
- Chung, S.O., A.D. Ward and C.W. Schalk. 1992b. Evaluation of the hydrologic component of the ADAPT water table management model. Transactions of the ASAE 35(2):571-579.
- Cooper, R.L., N.R. Fausey and J.G. Streeter. 1991. Yield Potential of Soybeans Grown Under a Subirrigation/Drainage Water Management System. Agronomy Journal 83:884-887.
- Cooper, R.L., N.R. Fausey and J.G. Streeter. 1992. Effect of Water Table Level on the Yield of Soybean Grown Under Subirrigation/Drainage. J. Production Agriculture 5(1):180-184.
- Czartoski, B.J., L.C. Brown, N.R. Fausey, A.M. Brate, H.W. Belcher and R.L. Cooper. 1995. Marketing wetlands for profit. Pp. 367-372 In: Conf. Proceed. Versatility of Wetlands in Agric. Landscape. ASAE/AWRA.
- Drouet, M.P., F. Papineau and R.S. Broughton. 1989. Economic Analysis of Subsurface Irrigation, Maize, Quebec. ASAE/CSAE Paper No. 892138. Presented at the 1989 International Summer Meeting jointly sponsored by the American Society of Agricultural Engineers and the Canadian Society of Agricultural Engineering, Quebec, PQ, Canada, June 25-28, 1989.
- Fausey, N.R., L.C. Brown, H.W. Belcher and R.S. Kanwar. 1995. Drainage and water quality in the Great Lakes and Corn Belt states. In: Task Com. Rpt. on Effect of Agricultural Drainage on Water Quality in Humid Areas. J. Irr. Drain. ASCE. 121(4):283-288.

Fausey, N.R. and R.L. Cooper. 1994. Water table management for crop production and ground water quality protection. USDA Cooperative Research Information System. (Summary).
Fausey, N.R., and S.R. Workman. 1994. Use of a coupled wetland-agricultural ecosystem for water quality remediation. National Research Initiative Competitive Grants Program. (funded project).

Knisel, W.G., R.A. Leonard and F.M. Davis. 1992. The GLEAMS Model: Plant Nutrient Component. Part I. Model Documentation. USDA-Agricultural Research Service, Athens, GA. 47 pp.

Reyes, M.R., R.L. Bengston, J.L. Fouss and J.S. Rogers. 1993. GLEAMS hydrology submodel modified for shallow water table conditions. Transaction of the ASAE 36(6):1771-1778).

Skaggs, R.W. 1980. A water table management model for artificially drained soils. North Carolina Agr. Res. Ser., Bull. No. 267, North Carolina State University, Raleigh, N.C. 54 pp.

Skaggs, R.W., N.R. Fausey and B.H. Nolte. 1981. Water management model evaluation for north central Ohio. Transactions of the ASAE. 24(4):922-928.

Skaggs, R.W., M.A. Breve and J.W. Gilliam. 1994. Hydrologic and water quality impacts of agricultural drainage. Critical Reviews in Environmental Science and Technology, 24(1):1-32.

Ward, A.D., E. Desmond, N. R. Fausey, T. J. Logan, and W. G. Knisel. 1993. Development studies with the ADAPT water table management model. IN:Proc. ICID Workshop on Subsurface Drainage Simulation Models. The Hague. September 4 and 5, 1993, pp 235-245.

Ward, A.D., N.R. Fausey, R.L. Cooper, and E.D. Desmond. 1987. Measuring Water Quality Discharges From a Soybean Subirrigation Project. Proceedings of the Third International Workshop on Land Drainage, Dec. 7-11, 1987, Columbus, OH. pp. G67-G79.

Workman, S.R., N.R. Fausey, L.C. Brown and P. Bierman. 1995. Coupled wetland-agricultural ecosystem for water quality remediation. Pp. 159-168 In: Conf. Proceed. Versatility of Wetlands in Agric. Landscape. ASAE/AWRA.

Publications

5. Conference Proceedings

Atherton, B.C., L.C. Brown, N.R. Fausey, L. Tornos, R.M. Gehring, J.R. Steiger, G.S. Hall, J.M. Patterson, J.J. Prenger, A.M. Brate, T.L. Zimmerman. 1998. Development of a comprehensive agricultural water management guide for Ohio. In: Proceedings of the 7th International Drainage Symposium. Vol. 7:02-98, ASAE: St. Joseph, MI. Pp. 713-723.

Brown, L.C. (Editor). 1998. Drainage in the 21st Century: Food Production and the Environment. Proceedings of the 7th International Drainage Symposium. Vol. 7:02-98, ASAE: St. Joseph, MI. 738 pp.

Brown, L.C., B.J. Czartoski, N.R. Fausey, and H.W. Belcher. 1998. Integrating constructed wetlands, water supply reservoirs, and subirrigation into a high yield potential corn and soybean production system. In: Proceedings of the 7th International Drainage Symposium. Vol. 7:02-98, ASAE: St. Joseph, MI. Pp. 523-529.

Brown, L.C., B.M. Schmitz, M.T. Batte, C. Eppley, G.O. Schwab, R.C. Reeder, D.J. Eckert. 1998. Historic drainage, tillage, crop rotation, and yield studies on clay soils in Ohio. In: Proceedings of the 7th International Drainage Symposium. Vol. 7:02-98, ASAE: St. Joseph, MI. Pp. 456-464.

6. Other Publications

Brown, L.C., B.J. Czartoaki and N.R. Fausey. 1997. Integrating constructed wetlands, water supply reservoirs, and subirrigation into a high yield potential corn and soybean production system. ASAE Paper No. 972038. Presented at the 1997 ASAE Annual International Meeting, Minneapolis, MN., St. Joseph, MI. 8 pp.

Patterson, J.M., B.C. Atherton, L. Tornos, R.M. Gehring, J.R. Steiger, J.J. Prenger, L.C. Brown, T.L. Zimmerman, G. Hall and N.R. Fausey. 1997. Modeling drainage response and recommendations for a modern agricultural water management guide. ASAE Paper No. 972125. Presented: 1997 ASAE Annual International Meeting, Minneapolis, MN., St. Joseph, MI. 20 pp.

Prenger, J.J., K.R. Mankin, B.C. Atherton and L.C. Brown. 1997. Using long-term weather records to generate complete DRAINMOD climate input files. ASAE Paper No. 972127. Presented: 1997 ASAE Annual International Meeting, Minneapolis, MN., St. Joseph, MI. 8 pp.

Schmitz, B.A., L.C. Brown, D. Eckert, R.C. Reeder, M.T. Batte and C. Eppley. 1997. Twelve years of drainage, tillage, crop rotation, and yield studies on a Hoytville silty clay loam in Ohio. ASAE Paper No. 972126. Presented: 1997 ASAE Annual International Meeting, Minneapolis, MN., St. Joseph, MI. 10 pp.

SYNOPSIS

Project Number: C-04

Start. 09/97

End. 09/99

Title: Degradation of Groundwater Quality from Pumping-Induced Surface-Water Infiltration:
Bacterial Contamination

Investigators: Jonathan Levy, Miami University, Oxford, OH 45056
Robert H. Findlay, Miami University, Oxford, OH 45056
Anthony J. Rossman, Miami University, Oxford, OH 45056
Heidi L. Schran, Miami University, Oxford, OH 45056
Kerang Sun, Miami University, Oxford, OH 45056
Amy Lustig, Miami University, Oxford, OH 45056

Congressional District: Eighth

Focus Category: ECL, G&G, GW, HYDGEO, HYDROL, MOD, NPP, ST, WQL, WS

Descriptors: Autochthonous-allochthonous microbial interactions, Bacterial transport,
Groundwater quality modeling, Surface-groundwater relationships.

Problem and research objectives: Drinking water pumped from shallow glacial-fluvial aquifers may be contaminated with fecal coliform bacteria derived from nearby polluted surface waters. Municipal wells located adjacent to polluted streams and rivers are especially susceptible to contamination. Due to downward hydraulic gradients induced by pumping, contaminated surface water may be drawn into the underlying aquifer and move towards drinking-water wells. Under US EPA guidelines, wells less than 50 ft from surface water are considered under the direct influence of surface water. From a regulatory standpoint, the Ohio EPA mandates that such groundwater be treated as if it were surface water and therefore requires the water to be treated with techniques for coagulation/flocculation, settling, filtration and disinfection. Upgrading typical groundwater treatment to include these techniques can be quite costly and in many circumstances prohibitive, resulting in well abandonment and the costly search for new water supplies. Studies in bacterial transport through groundwater suggest that the 50-ft criterion will not be cautious enough in some settings and too cautious in others. Adequate guidelines for appropriate separation distances need to be developed and should be based on our best ability to predict bacterial transport in a variety of hydrogeologic settings. Private wells are also susceptible to bacterial contamination. In a recent study of well-water quality in Iowa, 78% of wells in a volunteer sampling program were found to test positive for total coliform bacteria. The majority of these wells were shallow (67 percent) and were located > 100 ft from the closest active barnyard/feedlot and > 50 ft from a septic system (92 percent). Clearly, both rural populations obtaining drinking water from private wells and municipal populations obtaining drinking water from aquifers adjacent to polluted surface waters are at risk of waterborne disease. Our objective in this study is to help develop the ability to predict allochthonous (invasive, nonindigenous)

bacterial transport through groundwater aquifers, allowing greater protection of groundwater that is to be used as a drinking-water source.

Our overall research objective is to advance the ability to predict allochthonous bacterial transport and fate through groundwater aquifers. We note two main deficiencies with current models. The first is that the complexity of current models prohibits their use as regulatory tools for determining appropriate separation distances between bacterial sources and drinking-water wells. While the processes have been theoretically described, little work has been done toward their quantification or their relationship to real-world aquifers. Second, previous studies grounded in real complex systems have paid little attention to the impact of the interactions between allochthonous and autochthonous microbial communities of groundwater. Failure to predict retardation and immobilization or decay of allochthonous species accurately may be due to a failure to incorporate microbial interactions into existing models. With this research we directly address these two deficiencies. We approach the problem with a series of testable hypotheses, which we are investigating using a combination of laboratory column experiments under controlled and variable conditions and statistical and computer modeling, culminating in the development of a new bacterial-transport model. We also are initiating field studies to collect real-world data and test new models.

Hypothesis 1: The autochthonous microbial community significantly affects the transport of allochthonous bacteria through groundwater. The effects of autochthonous microbial communities on pathogenic bacterial transport result from predation and other ammensal or commensal interactions. These interactions result in either apparent decay or retardation of the allochthonous species. Autochthonous bacteria are part of a complex biofilm on aquifer sediments that also includes non-living organic matter. We wish to differentiate the effects of the organic matter from the living indigenous microbial community and we hypothesize that the interactions with autochthonous bacteria are significant apart from the effects of the nonliving biofilm component. Our experimental transport columns will therefore be treated to represent aquifer material with and without a viable autochthonous community and with and without any biofilm present. Apparent decay and retardation rates will be compared between treatments. We predict that interactions with the autochthonous community will result in an apparent difference in bacterial transport velocity compared to a conservative tracer and a decrease in the total number of allochthonous bacteria exiting the columns.

Hypothesis 2: A useful predictive model can be developed for allochthonous bacterial transport through aquifer sediments. In Year 2, we will build on the data generated through testing Hypothesis 1. Our goal is to be able to predict allochthonous bacterial transport and fate in groundwater given a set of biotic and abiotic aquifer characteristics. Developing this capability is a two-step process. In the first step, we will conduct dozens of column experiments in addition to those run for testing of Hypothesis 1, and we will measure the biotic and abiotic aquifer characteristics that influence bacterial transport and fate. The columns will comprise sediment taken from a variety of hydrogeological settings and will be run under controlled temperature conditions. For each column we will generate a bacterial breakthrough and dilution curve. In the second step, we will use a one-dimensional advection-dispersion-reaction model that simulates results comparable to the experimental curves. Each column will have its own associated model

parameter values. We will use multiple regression analysis to relate the calibrated transport-model parameter values to the aquifer characteristics that are most likely to control bacterial transport. The end result is a model which uses aquifer characteristics to predict bacterial transport and fate in a wide variety of settings. A strength of such a model is that it can incorporate the spatial variability and uncertainty of the aquifer characteristics to quantify the uncertainty associated with the final transport-model predictions.

Hypothesis 3: The bacterial-transport model developed in the laboratory will accurately predict bacterial transport in the field. We will begin development of a permanent field-test site. We have access to an abandoned City of Oxford, Ohio well that has sporadically tested positive for total coliform bacteria. The well is under the direct influence of Four Mile Creek. We will use the well to induce a vertical hydraulic gradient and use that gradient to perform conservative tracer tests and observe bacterial transport and fate along flow paths from the creek toward the well. A combination of single piezometers, nested piezometers and multilevel sampling devices will be used to determine the horizontal and vertical concentrations of chemical and microbiological components of groundwater. Biotic and abiotic aquifer characteristics will be determined from sediments recovered during piezometer placement. We will predict bacterial fate and transport using our model and the predictions will be compared to the observed bacterial concentrations.

Methodology:

Hypothesis 1: The autochthonous microbial community significantly affects the transport of allochthonous bacteria through groundwater.

Overview.

An experimental protocol using a new column design was established. This protocol will be used for a minimum of three replicates of each treatment. To start the experimental protocol, undisturbed groundwater sediments are collected using a drilling rig and split-spoon sampler. The sediment is collected into a 1.5-m x 3.4-cm inner diameter (ID) polycarbonate, split-spoon liner from which a 8-cm section is chosen. The ends of the sediment sample are sampled three times for phospholipid fatty acid (PLFA) analysis and the remaining sample is incorporated into a flow-through column apparatus. The sediment core is kept saturated throughout this process. A flow rate of 12-ml/hr is then established through the column to simulate local natural groundwater flow conditions. Bacterial and bromide breakthrough experiments are run by pulling a pulse of either bacterial suspension in natural groundwater or bromide solution through the column using a peristaltic pump. To avoid any affect the bromide might have on the autochthonous community, the bacterial breakthrough experiment is performed first. The column effluent is sampled in six-minute intervals using an autosampler, and the samples are analyzed with membrane filtration techniques. The pulse is followed by uncontaminated groundwater. The subsequent bromide breakthrough experiment is then performed with the assumption that bromide is a nonreactive tracer, and the effluent is analyzed using an ion specific electrode.

Data from the breakthrough experiments are reproduced with a computer analytical model of contaminant transport. Matching the model predictions to the bromide experiment data, velocity and dispersivity are determined. Knowing the pumping rate and velocity allows calculation of an effective porosity. The effective porosity is then used with the bacterial breakthrough experiment pumping rate to determine the groundwater flow velocity in that experiment. Using the computed velocity and the dispersivity calculated from the fitted dispersion coefficient from the bromide experiment, bacterial-reaction coefficients are determined by fitting model results to the bacterial-breakthrough data. To test Hypothesis 1, this process is repeated with replicates on intact undisturbed sediment (Treatment 1), after killing off the autochthonous microbial community (Treatment 2) and after removing the nonliving organic carbon (Treatment 3). The reaction coefficients obtained from each treatment will be compared using analysis of variance techniques.

Details of the methodology for Hypothesis 1 are given below.

Aquifer Sediment Collection

Undisturbed sediment cores are collected using a 1.5-m split-spoon sampler lined by 3.4-cm ID polycarbonate tubing. The samples are collected from a glacial-outwash, buried-valley aquifer in southwest Ohio. Miami University's Simco SK-2400 hollow-stem auger drill rig is used to auger to a depth of 4.6 m. This depth was chosen because it is at an elevation that is saturated year-round, yet during wet periods, it is still close to the water table where the highest biomass is likely to be present. Precautions are taken to minimize problems with heaving sands in the sampler. The sampler is driven 1.5-m below the bottom of the augers with a 63.5-kg hammer. Flexible plugs between the bit of the sampler and the liner are used to hold the sediment in the liner when the sampler is extracted from the drill hole.

PLFA Analysis

Once the sediment core is brought into the lab, three 10-cm³ samples are collected to determine the microbial community structure. The 1.5-m core is cut to expose the sediment surface at the desired sampling depth and the top centimeter is removed with a sterile spatula to insure a non-contaminated sample. One centimeter of sediment is removed from the core liner and placed into a 50-ml glass test tube containing 4.5-ml of 50-mM Potassium Phosphate Buffer (pH 7.4), 7.5-ml Dichloromethane (DCM) and 15-ml methanol. The test tubes are capped and shaken vigorously for 1 minute. The samples are kept at 4°C until further analysis.

After a minimum 24-hour settling period, 7.5-ml each of DCM and distilled water are added to the test tube containing the buffered sample. The tubes are shaken vigorously and kept at 4°C. After another 24-hour settling period, the samples are spun at 1500 rpm for 2 minutes, and the upper water/methanol phase aspirates until it is removed. Each sample is passed through a dried and weighed 2v Whatman filter into a 15-ml test tube. The filters are rinsed three times with 0.75-ml DCM. The sample solids are collected in the filters, dried at 100°C overnight and weighed. The liquid samples (total lipid), are dried with nitrogen at 35-40°C. During any prolonged procedural breaks, the samples are dissolved in 1-ml of DCM and stored at -20°C.

The phospholipid fraction of the sample is separated and collected using a 3-cm silica gel column and the dried lipid is suspended in 0.2-ml chloroform. First the neutral lipid fraction is removed with chloroform, then the glycolipid fraction is removed with acetone, and the phospholipid fraction is removed and collected with methanol. The phospholipid in methanol is dried under nitrogen at 35-40°C.

Once the phospholipids are fractionated, they are converted into fatty acid methyl esters (FAMES). The dried phospholipids are suspended in 0.5-ml of a 1:1 mixture of toluene and methanol. A solution of 0.2-N Potassium hydroxide is prepared and 0.5 ml is added to the phospholipid solution. The samples are vortexed, heated at 37°C for 15 minutes and cooled to room temperature. A 0.5-ml aliquot of 0.2-N acetic acid is added to each sample, the samples are immediately vortexed and 2-ml of both chloroform and deionized water (DI) are added to each. The samples are again vortexed for 1 minute and spun at 1500 rpm for 5 minutes. The lower phase containing chloroform and FAMES is transferred to a separate test tube. One ml of chloroform is added to the original test tubes to completely transfer all of the FAMES. The rinses are vortexed for 1 minute and spun at 1500 rpm for 5 minutes. The lower phase of each sample is transferred to the corresponding collection test tube. One ml of chloroform is added to the original test tubes, and the lower phases are transferred to the corresponding collection tubes. Ethyl ester standards (5µg of 20:0 and 5µg of 20:4ω6) are added to each sample and to 3 empty control test tubes for calibration. All samples and standards are dried under nitrogen at 35-40°C.

FAMES are purified using a C18 chromatography column. Empty 3-ml glass columns with Teflon frits are filled with 1-ml of dry JT Baker octadecyl resin. The columns are washed with DI water, methanol and chloroform. (All air bubbles are removed with pressurization.) The column is washed again with chloroform, ACN (acetonitrile) and a 1:1 ACN and DI water mixture. The samples are suspended in 0.25-ml ACN and the standards are suspended in 1-ml of chloroform. Once the samples are dissolved in ACN for 10 minutes, 0.25-ml of DI water is added. The samples are vortexed and loaded onto the column. The columns were rinsed three times with 0.25-ml ACN and DI water to ensure a complete transfer of the samples onto the columns. The columns are washed with 1-ml ACN, dried for 5 minutes under nitrogen pressure, rewashed with DI water and allowed to dry. The FAMES are removed from the column and collected with a 95:5 mixture of hexane:chloroform that is prepared that hour. The samples are dried under nitrogen at 35-40°C and suspended in 1-ml of hexane for gas-chromatographic (GC) analysis.

The FAME samples are suspended in 1-ml of hexane and transferred by three 0.5-ml hexane washes to a microvial. The samples are then dried under nitrogen at 35-40°C and suspended in 25-µl of hexane. A 2-µl aliquot of each sample is injected into a 5890 HP GC. The GC execution program ramps the column temperature from an initial temperature of 80°C to 250°C at a 4°C per minute rate and stays at 250°C for 10 minutes. The GC runs with hydrogen as the carrier gas and samples are detected with a flame ionization detector. Fatty acids are identified by their coelution with standards and with GC MS. Phospholipid fatty acid analysis is conducted using principal component analysis in SYSTAT.

Column Set-up

The column assembly begins with an 8-cm subsection of the 1.5-m sediment core contained in the polycarbonate liner. The 8-cm sediment sample is selected by visual inspection to determine which part of the longer core is representative of the more conductive layers in the aquifer. Other selection criteria include no apparent disturbance of the sample, complete saturation and no large cobbles that may preclude flow through the column apparatus. The test-section of sediment is cut from the rest of the core using a Dremel tool and a cut-off wheel, and the cut surface is smoothed and leveled to ensure a good fit with the acrylic column ends.

The column ends are attached to the 8-cm section in a procedure designed to minimize sediment disturbance and to keep the core completely saturated at all times. The liner and sediment are capped at the top and inverted, and an aluminum screen mesh is attached to the bottom of the liner with a soldering iron. In this way, the liner and sediment can later be removed from the rest of the column assembly without disturbing the sediment structure. A custom-made acrylic bottom column cap is then attached to the liner. This is done while the core is submerged in water to prevent air entry; groundwater collected the same day from the local aquifer is used for submersion. The bottom cap contains ports for a bromide ion-specific electrode (ISE) and effluent tubing which are both attached to the bottom column cap. The ISE is calibrated before insertion. Teflon tape and a small amount of vacuum grease are applied to all connections to aid in assembly and ensure airtight seals.

Once the effluent tubing is attached, the column is returned to an upright position and the temporary top liner cap is removed. A sterile digging tool removes the top 4-cm of sediment, leaving the bottom 4-cm of sediment intact. Approximately 2 cm of groundwater are added to the top of the sediment and an acrylic top column cap with an influent port tubing and is secured over the liner. The entire column apparatus (a 4-cm sediment core, top and bottom acrylic caps, a bromide ISE and influent and effluent tubing) is clamped upright to a ring stand. The influent and effluent tubing are loaded into separate channels of a two-channel, low-flow Masterflex C/L peristaltic pump. The influent and effluent tubing are loaded into the same pump to maintain the same volume of water in the reservoir above the sediment sample. The end of the effluent tubing is connected to an autosampler. The column assembly is kept at 12°C to simulate a groundwater environment and the autosampler is kept at 4°C to prevent any bacterial growth or death before analysis.

Bacterial Suspensions

Two 50-ml aliquots of warm, aerated Luria Broth are inoculated with 2-ml of an *E. coli* culture. The aliquots are shaken and incubated at 37°C for 4 hours. Both cultures are transferred to the same sterile centrifuge bottle and spun at 8000 rpm for 20 minutes at 4°C. The supernatant pellet is removed and suspended in 150-ml of groundwater. The bacterial suspension (or slug) is spun at 8000 rpm for 20 minutes at 4°C, and the supernatant pellet is again removed and re-suspended in 150-ml of groundwater. Three 1-ml samples of the bacterial suspension are plated using a membrane filtration technique to determine the initial concentration of the bacterial slug suspension.

Bacterial Breakthrough Experiment

To start a bacterial breakthrough experiment, the level of uncontaminated groundwater in the top reservoir is lowered with a syringe to 1 mm above the sediment surface. It is necessary to leave some water in the reservoir to avoid air entry and yet a minimum is desired to prevent dilution of the subsequent bacterial slug. A sterile pipette is used to add approximately 10-ml of the bacterial suspension in the reservoir. Flow from the bacterial suspension container to the column is maintained for 360 minutes. At the end of the slug period, the column-top reservoir is emptied with a syringe and uncontaminated groundwater is re-added to the reservoir. New influent tubing is attached to prevent bacterial contamination of the groundwater. Column effluent is collected in an autosampler. At the end of the experiment, effluent samples are removed from the autosampler and sent to the microbiology lab for analysis using the membrane filtration technique.

Bromide Breakthrough Experiment

After each bacterial breakthrough experiment, a slightly modified procedure is repeated with a bromide solution to determine physical parameters of the sediment. After lowering the groundwater level in the reservoir to 1-mm above the sediment surface, a 10-ml slug of bromide solution is added to the reservoir. This slug is drawn through the column with no other influent added. As the bromide solution approaches the sediment surface, 10-ml of groundwater is added to the reservoir and groundwater influent flow is resumed. In addition to collecting samples with an autosampler, bromide data are collected in-line with the bromide ISE in the bottom column cap. A software package called SensorLink from Orion, Inc. is used to interface the ISE to a laptop PC and convert the voltage measurements to bromide concentrations using pre-recorded calibration data. Bromide data are collected every minute.

Pasteurization Technique

To kill the autochthonous microbial community, a pasteurization technique is used. Groundwater in a 4.5-L beaker is heated to 80°C. The sediment core and liner are removed from the column apparatus and the ends are capped. The column is placed upright on a baffle in the heated groundwater for 15 minutes. The groundwater and core are allowed to cool to room temperature for 24 hours. The core is then placed in another beaker containing groundwater. The original groundwater is reheated to 80°C and the core is again submerged for 15 minutes.

Membrane Filtration

Samples from the bacterial breakthrough experiment are vortexed and diluted in sterile DI water. One ml of diluted sample is pulled through a 0.47- μ m Millipore filter using a Gelman membrane filtration apparatus and a vacuum pump. The filters are transferred to a pad placed on the lid of a 47mm mENDO agar plate. The pad is soaked with 1.5-ml of Lauryl Tryptose broth. The plates are incubated at 37°C for 2 hours. After incubation, the filters are transferred from the pad to mENDO agar and incubation continued at 37°C for another 22 hours. *E. Coli* colonies are enumerated by counting colonies with green metallic sheens. The total number of colony forming units per milliliter of sample is determined by dividing the number of colonies by the dilution factor.

Bromide Analysis

Bromide is analyzed using two different methods. For the most of the testing, an in-line, bromide ion-specific electrode (ISE) was used. To confirm the ISE results, a Dionex DX500 high performance liquid chromatograph (HPLC) has also been used with PeakNettm software. For HPLC analysis, the samples taken from the autosampler are centrifuged on the lowest setting for 5 minutes to remove small sediment from suspension. The samples are transferred by a micropipette to 0.5-mL sample vials. The vials are loaded into the HPLC autosampler and analyzed.

Post-run Sediment Analysis

After completion of the bacterial and bromide breakthrough experiments, the columns are broken down and the sediment is analyzed for grain-size distribution. Organic carbon content is determined with sediment from the core not included in the column. The organic carbon content is determined by furnace-heating. About 50-g of the aquifer material is placed in a furnace at 105°C for 24 hours to remove any water. After drying, the samples are re-weighed. The dried samples are put in the furnace at 500°C for another 24 hours, allowed to cool in a desiccator and re-weighed to give the mass of ignited sediments. The sediment organic carbon content is calculated as the ratio of mass loss to the mass of furnace-dried sediment.

Curve Matching

CXTFIT2.0 (Toride et al., 1995) is used to simulate the breakthrough experiments and reproduce the data. This program is a public domain code that is an extension and update of an earlier version by Parker and van Genuchten (1984). The program CXTFIT2.0 can be used to estimate parameters in several models of steady one-dimensional flow through calibration to observed laboratory or field data. These models can be solved using either a forward, trial-and-error or inverse approach. The inverse problem is solved by minimizing the sum of the squared differences between observed and predicted concentrations. The objective function is optimized using a nonlinear least-squares inversion method by Marquardt (1963).

The bromide breakthrough data are fitted with both an equilibrium and a non-equilibrium, two-region model. The governing equation of the equilibrium model is:

$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2} - v \frac{\partial C}{\partial x} \quad (1)$$

where

C is the resident concentration [ML^{-3}]

D is the dispersion coefficient [L^2T^{-1}]

v is the average pore-water velocity [LT^{-1}]

x is the distance [L]

t is time [T]

The governing equation for the nonequilibrium, two-region model is:

$$\theta_m \frac{\partial C_m}{\partial t} + \theta_{im} \frac{\partial C_{im}}{\partial t} = \theta_m D_m \frac{\partial^2 C_m}{\partial x^2} - \theta_m v_m \frac{\partial C_m}{\partial x} \quad (2-1)$$

$$\theta_{im} \frac{\partial C_{im}}{\partial t} = \alpha (C_m - C_{im}) \quad (2-2)$$

where

the subscripts *m* and *im* refer to the mobile and immobile region, respectively

α is the first-order mass transfer coefficient between the two regions [T^{-1}]

θ_m is the water content of mobile region

θ_{im} is the water content of immobile region

$\theta = \theta_m + \theta_{im}$ is the total water content

Since the two-region model represents the bromide breakthrough data better than the simple equilibrium model, the two-region model has been chosen for all future bromide modeling. In the two-region model, the slug concentration and slug duration time are entered as constant input parameters. The slug duration time is calculated as the ratio of the slug volume to the monitored effluent flow rate (*Q*). Since the background concentration of bromide in the groundwater used in the experiment was very low, the initial concentration was set to zero. Values for the groundwater flow velocity (*v*), the dispersion coefficient (*D*), the first-order mass transfer rate between the mobile and immobile regions (α) and fraction of mobile region (β) were obtained through model calibration to the breakthrough data. β is defined as:

$$\beta = \frac{\theta_m}{\theta_m + \theta_{im}} \quad (2-3)$$

The effective porosity of the aquifer sediments is calculated using the measured *Q*, and fitted value of *v*. The dispersivity is calculated using the fitted values of *v* and *D*. The effective porosity and dispersivity are physical properties of the aquifer sediments and remain constant for the bromide and bacterial breakthrough experiments.

We are using an advective-dispersive-sorptive model with a decay term to fit the bacterial breakthrough data. The governing equation for this model is:

$$R \frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2} - v \frac{\partial C}{\partial x} - \mu C \quad (3-1)$$

$$R = 1 + \frac{\rho_b K_d}{\theta} \quad (3-2)$$

$$\mu = \mu_l + \frac{\rho_b K_d \mu_s}{\theta} \quad (3-3)$$

where

R is retardation factor

K_d is the equilibrium sorption coefficient [$M^{-1}L^3$]

ρ_b is the bulky density of sediment [ML^3]

μ_l is the first-order decay coefficient for the solute in the liquid phase [T^{-1}]

μ_s is the first-order decay coefficient for the solute in the adsorbed phase [T^{-1}]

μ is the combined first-order decay coefficient [T^{-1}]

The input parameters for the model are the measured input concentration of the bacterial slug, the measured slug duration time, and the fixed values of v and D that are calculated based on effective porosity and dispersivity values obtained through curve matching the bromide breakthrough data.

These parameters are kept constant for all simulations. The input concentration of slug is obtained via membrane filtration. The slug duration is determined during the experiment. The initial concentration of allochthonous bacteria in the column is set to zero. The average linear groundwater velocity, v , for the bacterial experiment is calculated as the ratio of the measured pumping rate to the cross-sectional area times the effective porosity of the sediment core. The dispersion coefficient is calculated as v times the dispersivity of the aquifer sediments. The only calibration parameters are the apparent retardation factor and the first-order decay rate coefficient. The apparent retardation factor accounts for reversible sorption of bacteria during transport. The first-order decay rate is a phenomenological parameter that lumps together many processes including natural die-off of bacteria, bacteria immobilization resulting from irreversible sorption and straining, and possibly predation by protozoa or other grazers.

Hypothesis 2: A useful predictive model can be developed for allochthonous bacterial transport through aquifer sediments. In Year 2, we will investigate the factors that affect the transport of allochthonous bacteria through groundwater sediments. These factors will be quantifiable aquifer system characteristics. The primary factors affecting allochthonous bacterial transport include the grain-size distribution of aquifer material, grain surface coatings such as organic matter and iron oxides, groundwater chemistry including the ionic strength and pH, the cell size of allochthonous bacteria, and possibly the concentration and distribution of autochthonous bacteria. We will run many bacterial and bromide breakthrough experiments on sediment cores collected from a variety of locations. The procedures for running the experiments, quantifying the autochthonous microbial community and fitting the breakthrough curves will be the same as described for Hypothesis 1. Upon completion of the flow-through experiments, the column sediments and/or sediments from the original cores close to the column sediments will undergo abiotic characterization including analyses of grain size, mineralogy and organic carbon. We will then perform multiple linear regression analysis to relate calibrated transport model parameter values to aquifer characteristics. Various regression models will be explored for good fits. Forward selection and backward elimination procedures will be employed. Correlation between possible independent variables will be investigated. Only those variables with t-ratios > approximately 2.0 will be included in the final regression models. Equation robustness to changes in variable inclusion will be considered. To improve fits, transformations on the regression variables will be explored including logarithmic, square root and reciprocal transformations. Multiple linear regression models will be selected on the basis of the highest R^2 value with statistically significant variables. Plots of standardized residuals versus the fitted dependent variable value will be examined to judge the model fit. This statistical model development will

require between 30 and 50 column experiments encompassing a range of aquifer and pore-water characteristics.

Hypothesis 3: The bacterial-transport model developed in the laboratory will accurately predict bacterial transport in the field. In Year 2, we will develop a field site in the Four Mile Creek basin near Oxford, Ohio for eventual field-testing of our model. The site will use a drinking-water well formerly operated by the City of Oxford. The well is set in a 12-m layer of heterogeneous, permeable, glacial outwash deposits. A dense, clayey glacial till underlies the outwash, confining groundwater flow. The pumping well is a Ranney® collector with horizontal, screened collector arms, installed at depth and radially extending out from a vertical caisson. Water is drawn from the adjacent Four Mile Creek. Water from this well has sporadically tested positive for fecal coliform bacteria. The field area near the Ranney® collector provides an excellent site for investigation of bacterial transport through groundwater. We will use a single radial arm of the Ranney collector to induce a hydraulic gradient and use that gradient to perform conservative tracer tests and observe bacterial transport and fate along flow paths from the creek toward the pumping well. Field data will be used to test the modeling approaches presented.

A combination of single and nested piezometers and multilevel sampling devices will be used to determine hydraulic conductivities and the horizontal and vertical concentrations of chemical and microbiological components of groundwater. Hydraulic conductivities will be investigated using an aquifer pumping test, piezometer slug tests and laboratory permeameters. The pumping test will use the radial arm parallel to the creek. The slug tests will be performed by instantaneously releasing induced air pressure that depresses the water levels in the piezometers. The slug-test apparatus will consist of an airtight cap that fits over the top of the monitoring wells, a port for the pressure transducer cord, a port for a sensor wire, and a port for an air valve. The air valve will be connected by flexible hose to a gauge and an air compressor. A sensor will be lowered to the depth of the maximum induced head change. When the water is depressed to this desired level, the sensor will turn on an indicator light. A quick-release valve in the cap will allow instantaneous release of the induced air pressure. A pressure transducer located at the base of the well will measure the head which, in turn will be recorded by a data logger. All slug tests will be rising head tests.

Sediments withdrawn at the time of piezometer placement will be analyzed to determine chemical and biological parameters necessary for the model. The multilevel samplers will be used for closely-spaced vertical measurements of both head and concentration necessary to accurately determine contaminant transport. Approximately 10 single and nested piezometers and four multilevel samplers with five to ten sampling ports per well will be installed in a rectangular array between Four Mile Creek and the lateral Ranney arm that runs parallel to the creek. Forced-gradient tracer tests will be performed using a bromide solution. Approximately 100 liters of groundwater with a bromide concentration of 180 mg/l will be injected into 3 piezometers placed directly below the Four Mile Creek bed. Bromide will be used as a conservative tracer because of its low background concentration in the aquifer. The injection wells will be located so that they are directly upgradient of the multilevel sampling array under pumping-induced gradients. Based

on our experience with this aquifer, expected travel time from the creek to the radial arm is one to two days. Samples will be collected and brought to the laboratory for bromide analysis with the HPLC. Moment analysis on bromide concentrations will be used to determine the movement of the center of mass for velocity determination and the change in concentration variance for determination of apparent longitudinal dispersivity. Using these data we will predict allochthonous bacterial distribution within the flow path. Concurrent with the bromide tracer studies the distribution of allochthonous bacteria within the flow field will be determined and compared with model predictions.

Principal findings and significance:

Hypothesis 1

To test our hypothesis that the indigenous microbial community has interactions that significantly affect the survival and retardation rates of invasive pathogens in groundwater, a new type of column apparatus was designed, constructed and tested. The design allows for natural sediment to be used in a controlled laboratory setting without disturbing the physical structure of the aquifer sediments or the autochthonous microbial community. These features are essential for investigating the role of the indigenous microbial community on the transport of invasive bacteria.

The column apparatus, along with a technique to kill the indigenous microbial community, will allow us to set up two treatments for our experimental design. The third and fourth treatments that were set up to investigate our hypothesis that the interactions with the autochthonous community are significant apart from the effects of the nonliving biofilm component will be performed on the sediments once the second treatment has been successfully implemented on all replicates.

The column apparatus was tested and verified using conservative tracer (bromide) breakthrough experiments. Breakthrough curves were very reproducible and yielded reasonable values for velocity, dispersivity and effective porosity. Once it was determined that the column apparatus was working as designed, a column length appropriate for bacterial breakthrough experiments was determined. The sediment length would ideally be as long as possible and still allow enough bacteria in the effluent to allow accurate curve matching. Our initial column breakthrough experiments for bacteria using 10-cm-length cores were plagued by very high attenuation; the bacterial count was below that of the detection limit. In an effort to maximize the effluent bacterial count, we began using 4-cm-length cores in our column apparatus. We have since begun sampling somewhat coarser material, and based on the filtration theory of bacterial transport, we now believe that we will be successful with 10-cm-length cores. Testing has begun to confirm that the 10-cm column length will produce bacterial counts in the effluent that are adequate for analysis.

Results are presented for a 4-cm-long sediment core that had undergone all our latest setup techniques. Bromide and bacteria breakthrough curves for the sediment core were collected on April 2, 1998. CXTFIT2.0 was used to simulate the column experiments and fit

phenomenological coefficients to the data through automatic and manual curve matching. Figure 1a shows the bromide breakthrough data and the CXTFIT2.0 predictions using the classic advection-dispersion model assuming equilibrium and no reactions (Equation 1). Figure 1b shows the same data fitted using the nonequilibrium two-region model (Equation 2). Table 1 lists the input parameters for both models. Note that some of the parameters values are laboratory-determined and others are estimated through model calibration. While both models provide excellent fits to the observed data, the two-region model is a slightly better fit as indicated by the higher R^2 values (Table 1). Due to the better fit, the values derived from calibration of the two-region model are those applied to the subsequent bacterial breakthrough experiment.

Table 1. Parameter values for bromide transport models

<i>Parameter</i>	<i>Equilibrium Model</i>	<i>Two-Region Model</i>	<i>Method of Determination</i>
Initial concentration (ppm)	198.81	198.81	Lab-measured
Slug duration (min)	49	49	Lab-measured
Velocity (cm/min)	0.0608	0.0511	Calibration
Dispersion (cm ² /min)	0.0423	0.0217	Calibration
Mobile-region fraction	NA*	0.74	Calibration
Mass transfer rate (min ⁻¹)	NA*	0.0625	Calibration
R^2	0.997	0.989	Calibration

*NA indicates not applicable to that model

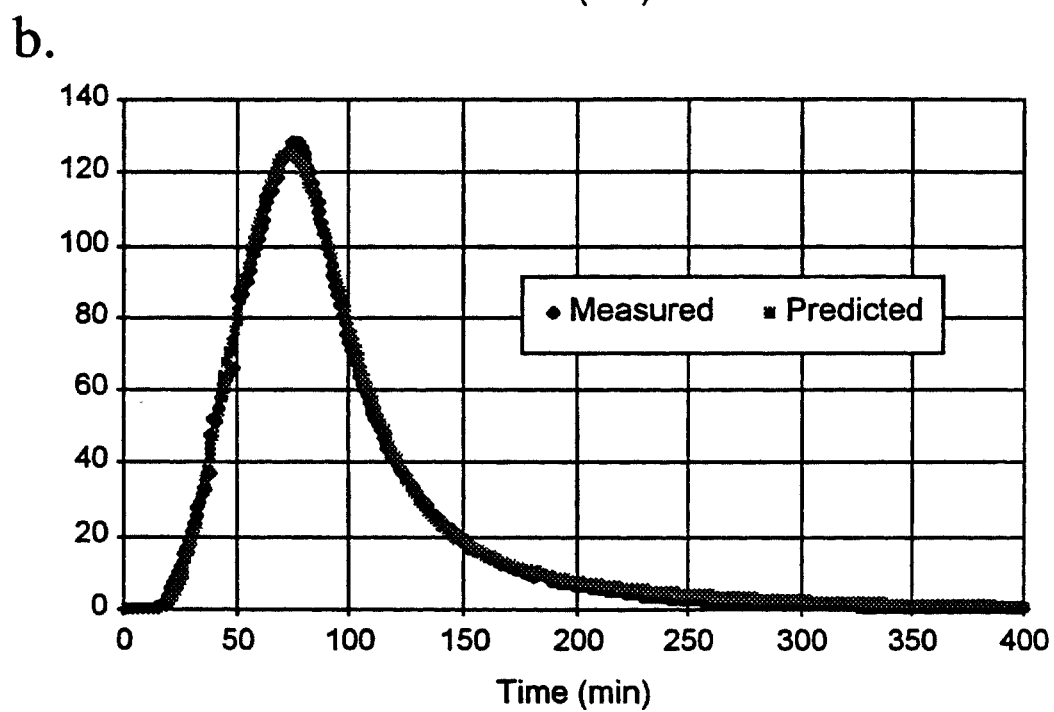
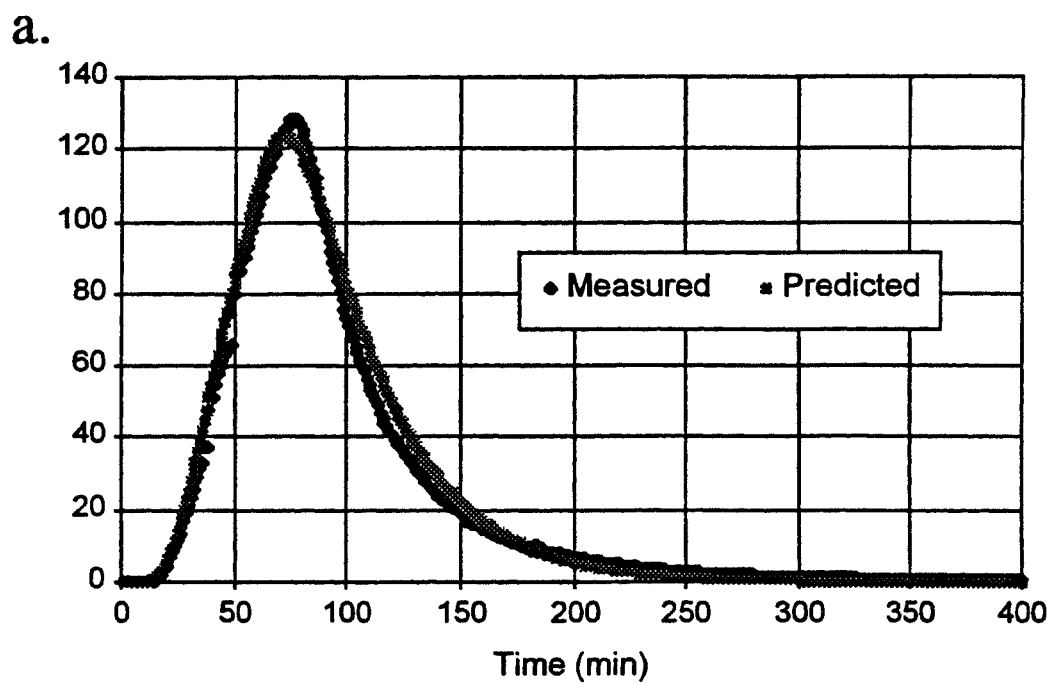


Figure 1. Bromide breakthrough data and model predictions for a) the equilibrium model and b) the nonequilibrium, two-region model.

Dispersivity and effective porosity of the sediments were calculated from the fitted velocity and dispersion coefficients. The effective porosity is the pumping rate divided by the velocity times the cross-sectional area of the sediment core and the dispersivity is the dispersion coefficient divided by the velocity. Values for the effective porosity and dispersivity were calculated to be 0.306 and 0.425 cm, respectively.

The bacterial breakthrough experiment was run at a slightly different pumping rate than the bromide experiment. Knowing the effective porosity of the sediment, however, allowed calculation of the water velocity which, in conjunction with the dispersivity, allowed calculation of the appropriate dispersion coefficient. Figure 2 shows the results for bacterial breakthrough experiment and the model predictions. Table 2 lists the values for input parameters used in the bacterial-transport modeling.

Table 2. Parameter values for bacterial-breakthrough experiment

<i>Parameter</i>	<i>Value</i>	<i>Method of determination</i>
Input concentration	6×10^8	Lab-measured
Slug duration (min)	360	Lab-measured
Velocity (cm/min)	0.0774	Bromide calibration
Dispersion coefficient (cm ² /min)	0.0329	Bromide calibration
Retardation factor	1.61	Bacterial calibration
First-order decay coefficient (min ⁻¹)	0.0271	Bacterial calibration

Note on Figure 2 that the match between the observed data and predicted concentrations is very good until the falling limb of the breakthrough curve. Apparently the bacteria stopped coming through the column sooner than expected. The reason for the discrepancy is unknown. Possible explanations include natural die-off or bacterial sedimentation in the influent reservoir or bacterial adsorption to experimental apparatus. We are currently investigating the causes. When we use slug duration as a calibration parameter along with the retardation factor and the decay coefficient, the fit can be much improved as shown in Figure 3. The slug duration used in Figure 3 is 314.5 min; the rest of the parameter values are the same as those in Table 2. The fit is greatly improved and the R^2 is 0.977.

Whichever slug duration is used, the bacterial breakthrough experiment yields first-order decay and retardation coefficients that fit the observed data well. Further experiments for both Hypotheses 1 and 2 will help explain what biotic and abiotic aquifer characteristics these reaction coefficients depend on.

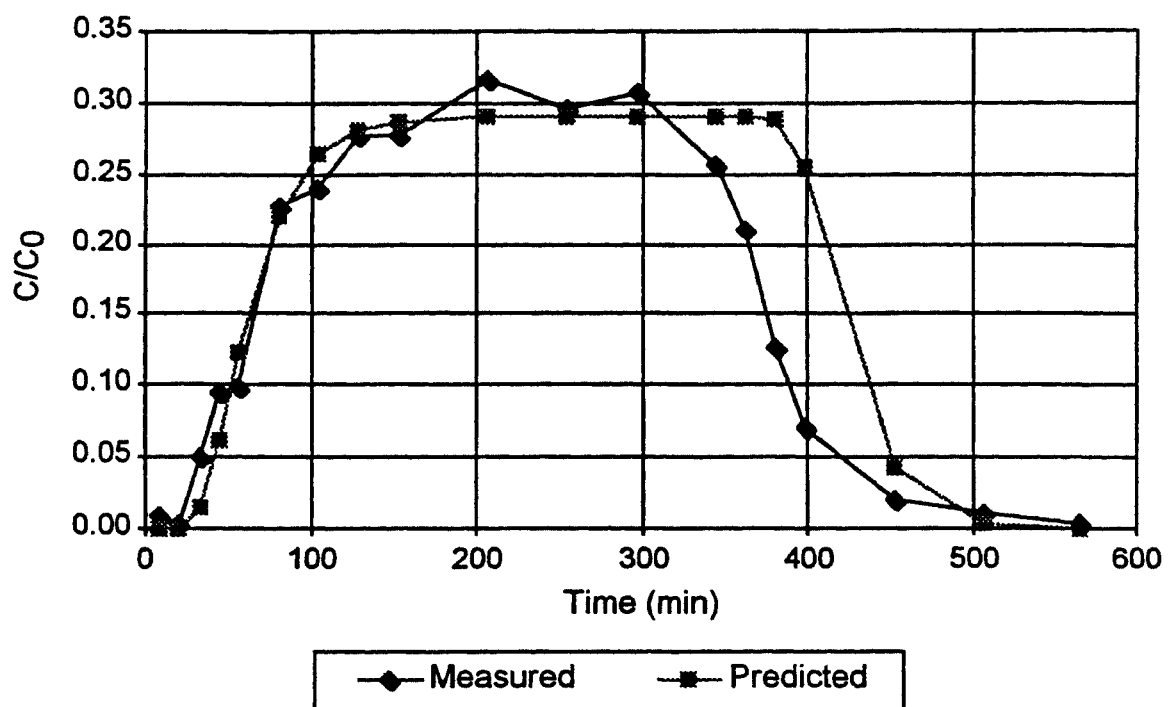


Figure 2. Bacterial breakthrough data and model predictions. Slug duration is fixed according to laboratory measurements.

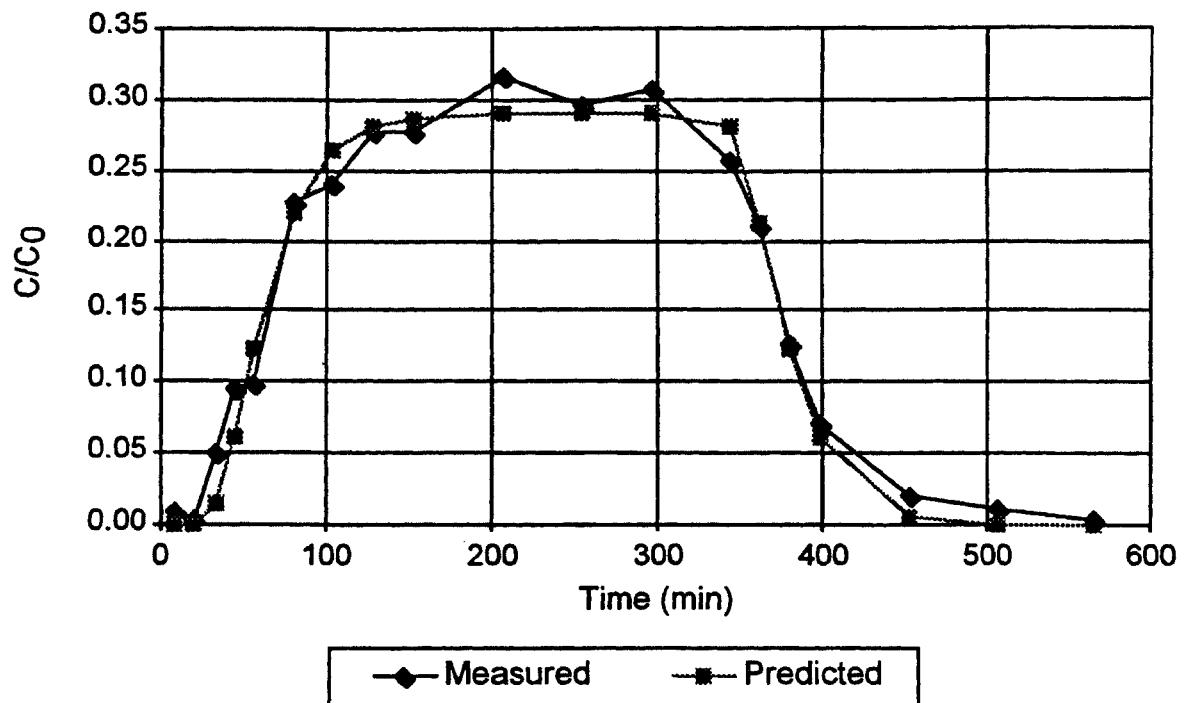


Figure 3. Bacterial breakthrough data and model predictions. Slug duration is used as a calibration parameter.

We are currently investigating a method to kill the autochthonous microbial community without disturbing the physical structure of the sediment or other organic matter present in the sediment. Criteria for the method are that 1) the method must kill the autochthonous community, 2) it must not alter the physical structure of the sediment and 3) it must not directly affect any subsequent allochthonous-bacterial breakthrough experiments through the same sediment. Our first approach was to flush a solution of mercuric chloride through the column followed by flushing with uncontaminated groundwater. While this technique killed the autochthonous community, enough mercury was left in the column after flushing with clean groundwater to kill allochthonous bacteria in the subsequent breakthrough experiment. We are now using a pasteurization technique to kill the autochthonous microbial community while preserving sediment structure. Preliminary results indicate that technique works effectively. Twice heating 4-cm sediment cores to 80°C successfully kills the autochthonous microbial community. A 10-g portion of an untreated core kept in groundwater at 4°C and a 10-g portion of a treated core were placed in two separate flasks with phosphate buffered saline. These were shaken at 200 rpm for 20 minutes at room temperature. A 0.1-ml aliquot of each were plated in duplicate on half-concentration Tryptic Soy agar plates and incubated at room temperature for 48 hours. The plate that was inoculated with the untreated sediment slurry had lawns of bacterial growth and the plates inoculated with treated sediment slurry showed no growth. These results suggest that pasteurization is an effective method of killing the autochthonous microbial community, and the technique has proven to be successful with 10-cm sediment cores as well. We are investigating the preservation of the sediment structure by running a bromide breakthrough experiment on sediment cores before and after pasteurization and comparing the resulting breakthrough curves.

Hypothesis 2

All the work described above leading to successful breakthrough experiments of bromide and bacteria constitutes progress for testing Hypothesis 2. It appears thus far that good model predictions of bacterial transport and fate through intact sediment cores can be made using a relatively simple model that includes linear equilibrium sorption (and thus a constant retardation factor) and a first-order decay coefficient. Now that much of the methodology has been established, many more experiments will be performed in the next year.

Hypothesis 3

So far, seven 3.18-cm in diameter piezometers with 1.52-m-length screens have been installed at the Ranney-well field site. The piezometers comprise 3 nests of two piezometers each and an additional single piezometer. Each nest comprises one piezometer screened just above the till layer underlying the outwash aquifer and a second, shallower piezometer screened so that the screen will intersect the water table under pumping conditions. Once the remaining nested monitoring wells are installed (planned for August 1998), exact placement of the multilevel sampling wells will be determined. Installation of the multilevel sampling wells and injection wells is planned for late August or early September 1998.

References

- Marquardt, D.W. (1963) An algorithm for least-squares estimation of nonlinear parameters, *J. Soc. Ind. Appl. Math.*, 11:431-441.
- Parker, J.C. and M.Th. van Genuchten (1984) Determining transport parameters from laboratory and field tracer experiments, *Bull. 84-3, Va. Agric. Exp. St.*, Blacksburg, VA.
- Toride, N., F.J. Leij and M.Th. van Genuchten (1995) The CXTFIT code for estimating transport parameters from laboratory or field tracer experiments, Version 2.0. Research Report No. 137, US Salinity Laboratory, Agricultural Research Service, US Department of Agriculture, Riverside, CA, 121 pp.

C. PUBLICATIONS

- Rossman, A.J., J. Levy and B. Findlay (1997) The influence of the indigenous groundwater microbial community on the transport of invasive bacteria. Abstract H21F-09. 1997 Fall meeting of the American Geophysical Union.
- Rossman, AJ, J Levy and R Findlay (1997) Determining the significance of the autochthonous (indigenous) microbial community in the transport of allochthonous (invasive) bacteria in groundwater. Abstract H42B-05. 1997 Spring meeting of the American Geophysical Union.
- Findlay, RH, H.L. Schran, A.J. Rossman, J. Levy (1998) Microbial community structure of a shallow groundwater sediment and coliform bacterial transport. Abstract for the Joint Meeting of the Ohio & West Virginia Branches of the American Society for Microbiology, April 24-25, 1998, Ohio State University, Columbus, OH.
- Findlay, RH, H.L. Schran, A.J. Rossman, J. Levy (1998) Microbial community structure of a shallow groundwater sediment. Eighth International Symposium on Microbial Ecology, August 9-14, 1998, Halifax, Nova Scotia, Canada.

Publications

Articles To Be Published In Refereed Scientific Journals

Miller, Penney, L., Yu-Ping Chin, 1998, Photoinduced Degradation of Carbaryl in a Wetland Surface Water, *in preparation to be submitted to Environmental Science and Technology*.

Miller, Penney, L., Yu-Ping Chin, 1998, Mechanisms Governing the Photochemical Transformation of Carbaryl in Aqueous Systems, *in preparation to be submitted to Environmental Science and Technology*.

Conference Proceedings

Miller, P. L. and Chin, Y.P. (1997) "Photoinduced Degradation of Organic Pesticides in Wetlands", *SETAC National Meeting*, San Francisco, November, 1997.

Miller, P. L. and Chin, Y.P. (1997) "Photoinduced Degradation of Agricultural Pollutants in Wetlands", *American Chemical Society National Meeting*, San Francisco, April, 1997.

Miller, P. L. and Chin, Y.P. (1996) "Photoinduced Degradation of Agricultural Pollutants in Wetlands", presented at the 19th *Annual Midwest Environmental Chemistry Workshop*, October 12-13, West LaFayette, IN.

Atherton, B. C., L.C. Brown, N. R. Fausey, L. Ternes, R.M. Gehring, J.R. Steiger, G.S. Hall, J.M. Patterson, J.J. Prenger, A.M. Brate, T. L. Zimmerman. 1998. Development of a comprehensive agricultural water management guide for Ohio. In: *Proceedings of the 7th International Drainage Symposium*. Vol. 7:02-98, ASAE: St. Joseph, MI. Pp. 713-723.

Brown, L.C. (Editor). 1998. *Drainage in the 21st Century: Food Production and the Environment*. *Proceedings of the 7th International Drainage Symposium*. Vol. 7:02-98, ASAE: St. Joseph, MI. 738 pp.

Brown, L.C., B.J. Czartoski, N. R. Fausey, and H.W. Belcher. 1998. Integrating constructed wetlands, water supply reservoirs, and subirrigation into a high yield potential corn and soybean production system. In: *Proceedings of the 7th International Drainage Symposium*. Vol. 7:02-98, ASAE: St. Joseph, MI. pp. 523-529.

Brown, L.C., B.M. Schmitz, M. T. Batte, C. Eppley, G.O. Schwab, R.C. Reeder, D. J. Eckert. 1998. Historic drainage, tillage, crop rotation, and yield studies on clay soils in Ohio. In: *Proceedings of the 7th International Drainage Symposium*. Vol. 7:02-98, ASAE: St. Joseph, MI. pp. 456-464.

Rossman, A.J., J. Levy and B. Findlay (1997) The influence of the indigenous groundwater microbial community on the transport of invasive bacteria. Abstract H21F-09. 1997 Fall meeting of the American Geophysical Union.

Rossman, AJ, J Levy and R Findlay (1997) Determining the significance of the autochthonous (indigenous) microbial community in the transport of allochthonous (invasive) bacteria in groundwater. Abstract H42B-05. 1997 Spring meeting of the American Geophysical Union.

Findlay, RH, H.L. Schran, A.J. Rossman, J. Levy (1998) Microbial community structure of a shallow groundwater sediment and coliform bacterial transport. Abstract for the Joint Meeting of the Ohio & West Virginia Branches of the American Society for Microbiology, April 24-25, 1998, Ohio State University, Columbus, OH.

Findlay, RH, H.L. Schran, A.J. Rossman, J. Levy (1998) Microbial community structure of a shallow groundwater sediment. Eighth International Symposium on Microbial Ecology, August 9-14, 1998, Halifax, Nova Scotia, Canada.

6. Other Publications

Brown, L.C., B.J. Czartoaki and N. R. Fausey. 1997. Integrating constructed wetlands, water supply reservoirs, and subirrigation into a high yield potential corn and soybean production system. ASAE Paper No. 972038. Presented at the 1997 ASAE Annual International Meeting, Minneapolis, MN., St. Joseph, MI. 8 pp.

Patterson, J.M., B. C. Atherton, L. Tornes, R.M. Gehring, J.R. Steiger, J.J. Prenger, L.C. Brown, T. L. Zimmerman, G. Hall and N. R. Fausey. 1997. Modeling drainage response and recommendations for a modern agricultural water management guide. ASAE Paper No. 972125. Presented at the 1997 ASAE Annual International Meeting, Minneapolis, MN., St. Joseph, MI. 20 pp.

Prenger, J.J., K.R. Mankin, B. C. Atherton and L.C. Brown. 1997. Using long-term weather records to generate complete DRAINMOD climate input files. ASAE Paper No. 972127. Presented at the 1997 ASAE Annual International Meeting, Minneapolis, MN., St. Joseph, MI. 8 pp.

Schmitz, B. A., L.C. Brown, D. Eckert, R.C. Reeder, M. T. Batte and C. Eppley. 1997. Twelve years of drainage, tillage, crop rotation, and yield studies on a Hoytville silty clay loam in Ohio. ASAE Paper No. 972126. Presented at the 1997 ASAE Annual International Meeting, Minneapolis, MN., St. Joseph, MI. 10 pp.

D . Information Transfer Activities

The Water Resources Center administratively is part of the Department of Civil and Environmental Engineering and Geodetic Sciences and is physically located in the Agricultural Engineering Building at The Ohio State University. This location provides numerous opportunities to work closely and share ideas with researchers in the College of Agriculture, the OSU Agricultural Engineering Cooperative Extension Service, the United States Agricultural Research Service, the Farm Science Review of Ohio, as well as the College of Engineering. A series of tasks were continued to transfer and disseminate information developed by researchers affiliated with the Water Resources Center to a wide range of state, federal, county and municipal agencies; the private sector, the academic community and private citizens throughout Ohio.

Water Luncheon Seminar

The Water Resources Center co-sponsored three Water Luncheon Seminar Programs for the seventeenth year to the water resources community in Central Ohio. These programs are developed cooperatively with The Ohio Department of Natural Resources (ODNR), the Ohio Environmental Protection Agency (OEPA), the Natural Resources Conservation Service (NRCS), the District Office of the United States Geological Survey (USGS) and Cooperative Extension Service The Ohio State University. These seminars attract 200 water resources professionals annually from federal, state, county and municipal agencies, the private sector and the academic community. These seminars provide a relaxed forum to discuss current state, federal and local water policy issues, problems, programs and research results. In addition to providing speakers for every sixth meeting, the Water Resources Center provides the administrative and financial support for the seminars. The Center also provides technical equipment and other support to assist the speakers with their presentations. The programs presented during the 1997 series follows.

Water Luncheon Seminar FY 1997

Date	Speaker/Agency	Topic
April 8, 1997	Donna Francy, U. S. Geological Survey	Re-growth of Fecal Indicator Bacteria and Implications for Assessment of Recreational Water Quality
October 14, 1997	Peter Finke, Division of Water Ohio Department of Natural Resources -	March 1997 Ohio River Flood - In Review
February 10, 1998	Dr. David Nash University of Cincinnati Natural Resources Conservation Service	Effective Discharge in Stream Sediment Transport

**Other Conferences and Seminars the Water Resources Center
Co-Sponsored or Supported in FY 1997**

Date	Program	Co-Sponsors
March 18-20, 1997	Project WET Facilitator Training	Ohio Water Education Program
May 16-17, 1997	Greenways Conference in Akron, OH	Greenways of Ohio, Water Management Association of Ohio, Water Resources Center
September 2-4, 1997	Project WET Facilitator Training	Ohio Water Education Program
November 13, 1997	Wayne Nichols Lecture	School of Natural Resources The Ohio State University
November 18-20, 1997	Water Management Association of Ohio Annual Conference	Water Management Association of Ohio

The Center's Director continued meeting with the leading state water resources officials to share information on current water management and policy issues; and to seek continued support for our water research program and disseminating the information and technology developed through this program and others at the universities throughout the state and region. A third of the phone calls to the Center are public information calls requesting information on water quality issues. A newsletter was mailed to 1,500 in the fall of 1997.

Researchers have presented their initial findings at national meetings as indicated by the list of abstracts in Part C. Both professors and students have participated in the information dissemination at regional, national and international conferences including the Ohio and West Virginia branches of the American Society for Microbiology, the Spring and Fall meetings of the American Geophysical Union and the Spring meeting of the International Symposium on Microbial Ecology.

The project by Levy, et al. has led to cooperation between Miami University, the US Geological Survey, Water Resources Division in Columbus, Ohio and the City of Cincinnati. The USGS personnel have been investigating similar questions the nearby Miami River buried-valley aquifer. The researchers are submitting a joint proposal with the USGS and the City of Cincinnati Water Works for funding from the Ohio Water Development Authority that will supplement and expand this research. Such cooperation will advance the goal of making findings known to researchers, regulators and managers.

In addition to the International professional meeting papers listed elsewhere, researchers on the project by Brown and Batte have made other presentations on the overall project scope, demonstration, monitoring and research plans: 1998 National Land Improvement Contractors meeting in Nashville, TN on February 18-19; Ohio Sea grant Program personnel at Ohio State University April 7; Water Seminar Luncheon sponsored by the Water Resources Center at Ohio State University on April 14, 1998.

A one-day technical session on the system was presented at the Overholt Drainage School at Ohio State University on March 20, with 35 contractors, consultants, engineers, extension agents and soil and water conservation technical agency personnel attending.

A poster presentation titled "innovative agricultural water management systems create a win-win for food production and environmental quality objectives" was presented at How Agricultural Science Research Serves the Nation: A University Exhibition and Reception on Capitol Hill, May 19, 1998, and a two-page handout was developed.

Water Management Association of Ohio (WMAO)

The Water Resources Center continued for the ninth year to be the administrative office for the Water Management Association of Ohio (WMAO). This not-for-profit, 300 member, state-wide organization promotes and supports the development, conservation, control, protection and utilization of the water resources of Ohio for all beneficial purposes. It is the only Ohio professional organization that is solely concerned with managing Ohio's water. The WRC provides staff support, office space and equipment to WMAO as a portion of the information transfer program. During this grant year a research project was developed to support the Center's activities on this project.

Ohio Water Education Program (OWEP)

The Ohio Water Education Program (OWEP) began in Ohio in the Fall of 1992 with the Ohio Department of Natural Resources and the Water Resources Center. A Memorandum of Understanding supporting this project has been signed by the Water Management Association of Ohio/Water Resources Foundation of Ohio, the Ohio Department of Natural Resources, the Ohio Environmental Protection Agency and the Water Resources Center. There are two functions to this program. The first provides a database of water education materials, projects, and supplies available for water education in Ohio. The second segment of this project is sponsoring Project WET - Water Education for Teachers. This is a national program for students in grades K-12 for interdisciplinary water resources education. The Center has donated office space, telephone and fax facilities, postage and provided substantial administrative support and services for this project. This project is a major part of the Center's information transfer program.

Two leadership training workshops were held in FY 1997 providing educators with information on Project WET. More than 80 teachers attended these two-day training workshops which consisted of hands-on projects. In the fiscal year there were 69 6-hour Project WET Workshops held in Ohio where 1,220 people received instruction and materials on Project WET. Since the program's inception in 1995, more than 3,800 teachers have been trained in 237 workshops. The number of Ohio students exposed to water education is at least 95,350, if you estimate each teacher reaches 25 students annually. In addition to providing administrative support, the Center staff gave numerous promotional presentations and demonstrations for the program. Further support to this activity was provided through the Water Resources Foundation of Ohio.

Cooperative Arrangements

Program Development

Section 104 of the Water Resources Research Act directs the Secretary of the Interior to administer program grants to Institutes and Centers established within the States and certain other similar jurisdictions for research, information transfer, and training that will assist the Nation in augmenting water-resources science and technology. Responsibility for administration of this program has been delegated to the U. S. Geological Survey (USGS).

Congressional conference committee language has changed the way Federal funds were awarded under the State Water Institute Program in fiscal year (FY) 1996. Funds will be awarded in two separate parts. One part directed a base grant (\$20,000) for each Institute (\$1.1 million) while the other part created a competitive grant program for the remaining funds (\$3.22 million). The Regional Competitive Grant Program (RCGP) application/solicitation review and selection process was coordinated by a lead Institute in each of four Regions.

The Ohio State Water Resources Research Program in Fiscal Year 1997 began with a Call for Pre-Proposals mailed to administrators and qualified faculty investigators at more than 40 private and public colleges and universities throughout Ohio. This announcement contained the research priorities identified for the 13-state North Central Region that was created by newly enacted legislation.

Federal Guidelines

Of the 500 proposal packages mailed to potential investigators, there were thirteen preliminary proposals submitted from five universities in Ohio. Central State University, an historically black university, was one of the colleges to which materials were sent, but they did not submit any pre-proposals.

Evaluation/Selection Procedures

Thirteen pre-proposals from five universities throughout the state were submitted for evaluation and consideration. These pre-proposals were subjected to a review by all of the members of the Water Resources Center's Advisory Committee. In addition, these pre-proposals were distributed to the various divisions within the principal state and federal water-related agencies in the State who serve on the Advisory Committee and their respective divisions reviewed the proposals. The four agencies included in this evaluation were the Ohio Department of Natural Resources, the Ohio Environmental Protection Agency, the District Office of the United States Geological Survey and the Agricultural Research Service in the United States Department of Agriculture.

The results of these reviews were presented at a meeting of the Advisory Committee where this panel selected four of the pre-proposals and instructed the Center's Director to request fully developed proposals from the investigators for submission to the North Central Region Competition. Of these selected pre-proposals, three of them were from The Ohio State University and one was from Miami University.

The four selected pre-proposals were developed more fully and were submitted as full proposals to Nebraska to the North Central Region for competition with projects from each of the other 12 states in the region. Four proposals was the maximum amount any state could submit to the regional competition. The 52 proposals were distributed to technical reviewers throughout the nation and ranked according to the points indicated by the technical reviews. The top twenty-five ranked projects in the region were then distributed to the Directors throughout the region for review. The Directors' considered the technical rankings, priorities of the region, fiscal budgets, thoroughness of the application, training and professional level of the principal investigator as they selected the top 15 projects to award. Ohio had three projects in the top 25 projects. Two of the projects ultimately received funding. Those projects were: Economic and Hydrologic Analysis of Integrated Wetland Reservoir and Subirrigated Agricultural Production Systems by Larry C. Brown and Marvin T. Batte of The Ohio State University, College of Food, Agricultural and Environmental Sciences; and; Degradation of Groundwater Quality from Pumping-Induced Surface-Water Infiltration: Bacterial Contamination by Jonathan Levy and Robert H. Findlay of Miami University, Oxford, Ohio.

Regional Cooperative Initiatives

The Ohio State University continues as a Charter Member of the Ohio River Basin Research and Education Consortium, and the Director of the Water Resources Center has continued to serve as one of the University's three representatives to the Consortium. The Director is a member of the Universities Council on Water Resources and participates in the regional and national meetings of the National Institutes for Water Resources. He is active in the North Central Region activities also.

Program Management

The Water Resources Center Director contacts the Principal Investigator on the research project to discuss progress, budgetary activity, and future activities. Progress Reports or Completion Reports are prepared by the Principal Investigator. The investigators are urged to publish the results of their findings in the technical literature of their major disciplines and in other journals that are appropriate to the topic of their research. They are also encouraged and invited to present their findings at the Water Luncheon Seminar that is a part of the information transfer program.

**Water Resources Center Advisory
Committee
College of Engineering**

Dr. L-S Fan
Chair, Chemical Engineering

Dr. E. Earl Whitlatch
Director, Water Resources Center

School of Architecture

Dr. Steven I. Gordon
City and Regional Planning

Professor John W. Simpson
Landscape Architecture

College of Biological Sciences

Dr. Jeffrey Reutter
Center for Lake Erie Area Research

Dr. David Culver
Zoology

**College of Mathematical and
Physical Sciences**

Dr. E. Scott Bair
Geological Sciences Department

College of Agriculture

School of Natural Resources

Dr. Robert L. Vertrees
Resource Management

**Ohio Environmental Protection
Agency**

Dr. John Estenik

**Ohio Department of Natural
Resources**

Michele Willis, Chief
Division of Water

United States Geological Survey

Steve Hindall
District Chief

**United States Department of
Agriculture**

Dr. Norman Fausey
Agricultural Research Service

E. Student Support

Training Accomplishments

Field of Study	Undergraduate	Masters	Ph.D.	Total
Food, Agricultural and Biological Engineering	4	1	1	6
Agriculture, Environment & Dev. Economics			1	1
Environmental Sciences	1	1	1	3
Geological Sciences		1	1	2
Totals	5	3	4	12

These research activities were accomplished with only RCGP Awards. The Base Grant has not been used in these activities but to continue the strong Information Transfer program of Water Resources Center.

G. NOTABLE ACHIEVEMENTS AND AWARDS

In April 1997, A.J. Rossman, one of the graduate students working on this project submitted a proposal to the Geological Society of America for funding of graduate-student research associated with this project. He was awarded \$1800 and his proposed research, which was closely connected with the research proposed in this project, was also one of 34 out of 478 to receive special recognition as having exceptional merit in concept and presentation.

In early 1997, Penney Miller, one the graduate students working on this project, submitted a proposal to the United States Environmental Protection Agency for the Science to Achieve Results (STAR) Graduate Student Fellowship to support her in her research efforts and her graduate studies. The STAR program was initiated in 1995 to encourage promising students in their academic and research pursuits in environmentally related fields. This fellowship, which is renewed annually according to a student's progress, offers up to three years of support. Penney was notified of her acceptance into the program in August of 1997 and is one of a hundred people across the nation chosen to receive this award.

In 1998, Penney Miller also was awarded the 1998 Environmental Chemistry Division of the American Chemical Society Graduate Student Award. More than 2,000 students applied for this prestigious award and it was awarded to only fifteen.